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VOL. 41. 1908. No. 190.

Proceedings of the Four Hundred and Seventieth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 20, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on February 6, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Thos. A. Rose. | Harry Snowdon.
C. N. Staniland.

From the class of Associates to that of Members :—

E. C. Daubeny. | F. Tremain.

From the class of Associates to that of Associate Members :—

C. F. B. Marshall. | Harry A. Nott.
Albert J. Smith.

From the class of Students to that of Associate Members :—

H. S. Binns.	B. C. Johnson.
Harold L. Brook.	C. H. Martin.
E. F. Cutforth.	John Palmer.
E. E. E. Dormann.	J. M. G. Rees.
Henry J. Golding.	Harold D. Symons.

Messrs. V. A. Fynn and J. O. Girdlestone were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

William Clark.	Albert George Lee.
Herbert Cooch.	William Upsall Lonnon.
George Francis Dewynter.	Frank Pape.
I. Harding Jenkins.	Harry Sydney Thompson.
Cecil Octavius Jolly.	Arthur Wallis.

As Students.

Stanley Moncœur Hills. | Ernest Pogson.
Estlin H. Webb.

Donations to the *Library* were announced as having been received since the last meeting from F. Kohlrausch, H.M. Patent Office, Messrs. S. Rentell & Co., Ltd., Messrs. E. & F. N. Spon, Ltd. ; to the *Building Fund* from A. D. Constable, S. Z. de Ferranti, Dr. C. V. Drysdale, K. Edgcumbe, W. M. Mordey, J. F. C. Snell, A. Stroh ; and to the *Benevolent Fund* from G. Allom, Major P. Cardew, M. S. Chambers, W. C. Clinton, P. R. Cobb, V. K. Cornish, H. C. Donovan, B. M. Drake, G. Draper, Dr. C. V. Drysdale, K. W. Edgcumbe, E. Garcke, Dr. R. T. Glazebrook, F. E. Gripper, H. G. Harris, Colonel H. S. Hassard, C. C. Hawkins, K. Hedges, J. S. Highfield, R. W. Hughman, E. S. Jacob, A. E. Levin, E. Manville, W. M. Mordey, Major W. A. J. O'Meara, Hon. C. A. Parsons, W. H. Patchell, A. H. Preece, T. Rich, S. R. Roget, G. H. Sayer, W. H. Scott, A. Siemens, A. Stroh, A. J. Stubbs, G. G. Tomkins, A. P. Trotter, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that the Council has decided that a Kelvin Lectureship shall be established for the Institution, and that a Kelvin Lecture be delivered annually ; the arrangements for the delivery of the first lecture will be announced in due course.

The following papers were read and discussed :—

ELECTRICAL POWER IN RAILWAY GOODS WAREHOUSES.

By H. HENDERSON, Associate Member.

Received from the NEWCASTLE LOCAL SECTION, *October* 12, 1907, *read at Newcastle on January* 13, *and at London on February* 20, 1908.*)

The introduction of electrical power into railway working has been attended with very great advantages, especially in the matter of dealing with goods traffic in warehouses. The advantage of electric lighting was proved years ago, and the late Mr. W. E. Langdon claimed that the work done in a given time was increased 30 per cent. by the installation of arc lamps in one of the Midland Company's warehouses. It is obvious that good lighting is essential where goods are being loaded and unloaded, and time is saved if the addresses can be distinctly read. In the North-Eastern Railway Company's Goods Warehouse in Forth Banks, Newcastle, hand lamps had to be employed on the benches when gas was in use. When arc lamps were introduced, the hand lamps were dispensed with, which was a considerable gain in the speed of handling goods, and also from the point of view of safety. The good lighting provided by the arc lamps also allows of better supervision of the material by watchmen, which results in a reduction in the number of claims. The use of electricity for power purposes is, however, of more recent date, and it is with the question of power that this paper deals.

Amongst the chief advantages to be gained are :—

1. More floor space available by making use of overhead travelling cranes.
2. Less aggregate power to perform the same work as hydraulic.
3. Less cost for power.
4. Reduction in cost of maintenance.

Nos. 1 and 2 are very clearly seen by examining Figs. 1 and 2. Fig. 1 is a plan of part only of the Forth Goods Warehouse. This shows the warehouse as originally designed for hydraulic power. The total number of hydraulic cranes per row of benches was 18, in three rows, making a total of 54. These cranes served benches with an approximate length of 1,500 ft. and an area of about 48,000 sq. ft., which gives 30·3 H.P. per 1,000 sq. ft. of bench area and a lifting capacity of 1·4 tons for the same area.

In the Company's new warehouse (Fig. 2) at New Bridge Street,

* On account of Lord Kelvin's death the reading of this paper in London was postponed from the meeting of Dec. 19, 1907.

Newcastle, which is designed for electrical working, four electric overhead travelling cranes, described later, serve two benches of a total length of 580 ft. and an area of about 15,000 sq. ft. These cranes give 6·13 H.P. per 1,000 sq. ft. of bench area, and a lifting capacity of 0·27 ton for the same area. These figures show what a great saving can be made by adopting such cranes, and that nine similar electric cranes could have replaced the fifty-four hydraulic cranes at the Forth

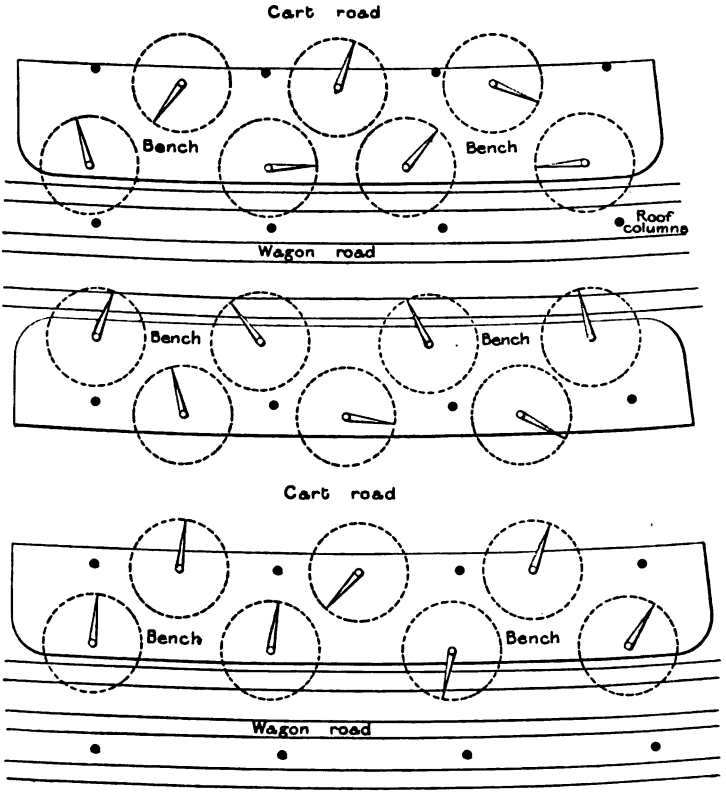


FIG. 1.—Showing Hydraulic Cranes, Forth Warehouse.

Goods Warehouse, where head room is ample for the use of overhead travellers. The figures cover all motions in each case.

The types of machinery used in a goods warehouse are :—

1. Machinery for dealing with goods, namely : cranes, hoists, etc.
2. Machinery for dealing with traffic, namely : capstans, hoists, and traversers.

In describing the different types, the new goods warehouse of the North-Eastern Railway at New Bridge Street will be taken as an

example, because it has been designed for electrical working, and the whole of the machinery is electrically driven.

Under heading No. 1, a type of crane has been adopted which seems to be most suitable for this class of work. It consists of an ordinary overhead travelling crane, but instead of being fitted with the usual crab, the hoisting gear is attached to a revolving jib carried on a lattice framework fixed to the crab.

The crane has thus four motions governed by two universal controllers fixed to a platform on the revolving jib. The jib, controllers, and hoisting gear are clearly shown in Fig. 3, which also shows

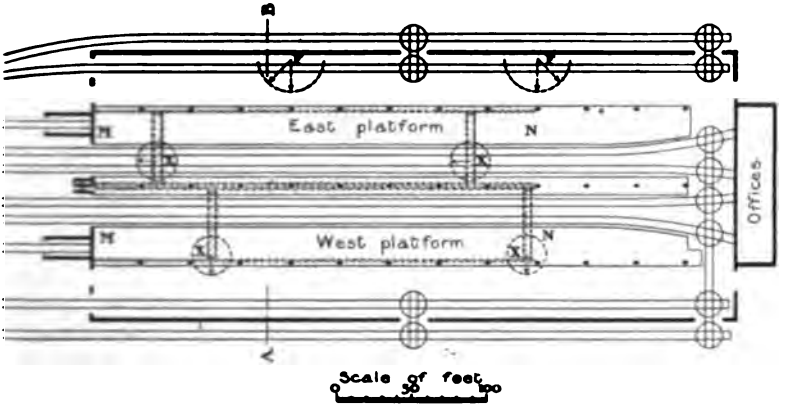


FIG. 2.—Ground Floor New Bridge Street Warehouse.

the method of suspension from the crab. The lifting capacity is 1 ton, and the sizes of the four motors are :—

Lifting motor, 15 B.H.P. at 150 ft. per minute.
Revolving motor, 1½ B.H.P. at 250 ft. per minute.
Cross traversing motor, 1½ B.H.P. at 150 ft. per minute.
Travelling motor, 5 B.H.P. at 350 ft. per minute.

The span is 48 ft. 6 in., and the jib radius 11 ft. From the cross-section of the building shown on Fig. 4, upon which these cranes are marked X, it will be seen that a jib can reach material outside the span of the main girders and do lifting work in three spans of the main building. This is a great advantage as material can be taken from any wagon and deposited on a cart irrespective of the position of either vehicle. Such work cannot be accomplished by any other type of crane, and at the same time the full command of the whole of the bench is obtained without in any way taking up valuable storage space.

Other cranes on the same floor include two wall cranes shown at F on Fig. 4. These are ordinary revolving jib cranes with stationary

machinery and a fixed driving platform. The machinery consisting of lifting and revolving gear with a separate motor for each motion is fixed on brackets above the top support of the crane, and the jib is revolved by a vertical shaft carrying a pinion, driving a spur wheel fixed to the top of the crane post. These cranes are capable of lifting 1 ton at a speed of 60 ft. per minute with 6 B.H.P., and of slewing at a speed of 150 ft. per minute with 1½ B.H.P. The motors are driven by a double controller with a single handle, as in use on the travelling cranes.

In the basement four cranes have been erected, and owing to the smallness of the head room, special types have been used. Two of the cranes are travelling jib cranes, similar to the ground floor. These are shown at E on Fig. 5 and in further detail on Fig. 6. In these cranes the revolving jibs are 12 ft. radius, and the span is 20 ft. They can thus cover a width of nearly 40 ft. and have a track 200 ft. long. The capacity is 1 ton and the sizes of the motors are:—

Lifting motor, 6 B.H.P. at 60 ft. per minute.
Revolving motor, 1½ B.H.P. at 150 ft. per minute.
Cross traversing motor, 1½ B.H.P. at 100 ft. per minute.
Travelling motor, 2¼ B.H.P. at 100 ft. per minute.

It will be seen that the hoisting gear is forward on the jib in this case and a heavy balance weight attached at the back. This is done to keep the controlling platform up, on account of the small amount of head room available. The remaining two cranes in the basement are of a special type, and are named revolving pillar cranes. They are shown at D in Fig. 5, and a full view of the crane and circular track is shown on Fig. 7. Each crane consists of a revolving framework, one end of which is constructed to encircle one of the main pillars of the building, whilst the other is fitted with wheels which run on a circular track attached to the roof. The cage and hoisting gear are fixed near the pillar to the revolving frame, and the travelling motor is at the outer end near the wheels, the two motions being driven from one controller. The pillar end of the frame runs on a heavy casting which, when bolted up, forms a vertical circular support carrying a square horizontal flange on the bottom. The end of the frame surrounds this support and carries two rollers which bear on the vertical surface, thus keeping the motion circular. These cranes are capable of lifting 1 ton at 60 ft. per minute with 6 B.H.P. and revolving at 150 ft. per minute with 1½ B.H.P.

For hoisting material to the top floors, which are used for storage of grain, flour, and similar materials, there are in use two transporters and six jiggers. The transporters travel the full width of the building at about 70 ft. from the ground-floor rail level, the track being extended 16 ft. on each side of the building to permit the hoisting of material from wagons outside the warehouse. These machines are shown at O in Fig. 4. The hoisting gear is contained in a travelling crab, which also carries the cage. The track is formed of heavy channel irons bolted to

the roof girders and to the concrete roof, the running rails being bolted to the bottom flange. The lifting is done with a 15-B.H.P. motor, at 150 ft. per minute, and the travelling with 1½-B.H.P., at 350 ft. per minute, both motors being driven from one controller. The lifting capacity is 1 ton. These hoists can pick up material from any part of the ground floor directly beneath them, and can deposit it on either of

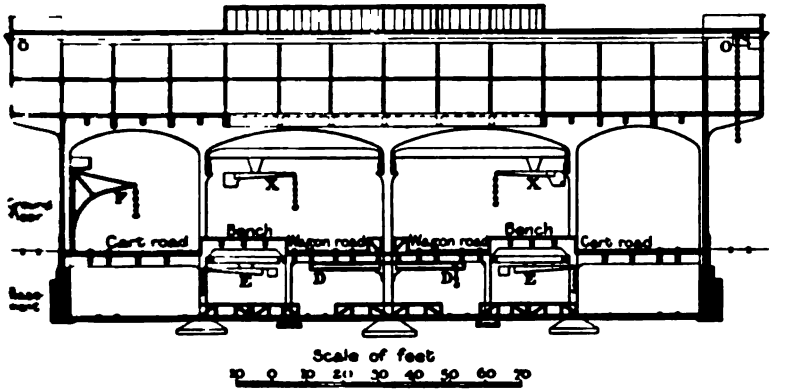


FIG. 4.—New Bridge Street Warehouse.

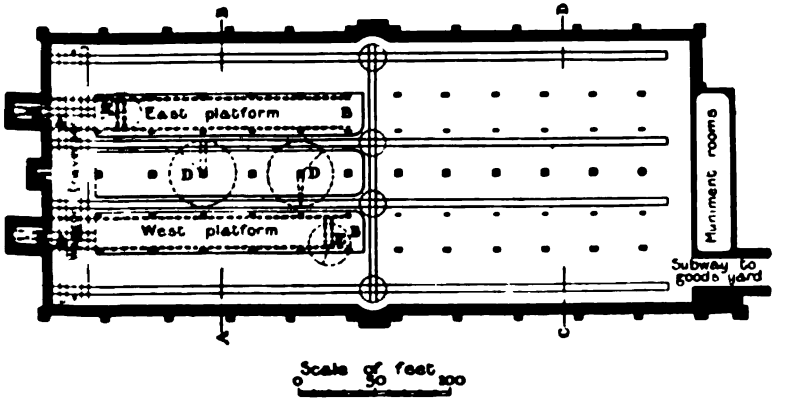


FIG. 5.—Basement, New Bridge Street Warehouse.

the upper floors, the wire passing through a slot in the floor when travelling from the well to the first floor. In the jiggers the machinery is fixed. A heavy H-iron is bolted to the roof, and along this travels a small framework for bringing in the load from outside either to the first or to the second floor, and in two cases to a third floor also. These hoists are shown in Fig. 8. The hoisting rope is permanently fixed at one end to the outer end of the girder, and passes through the

travelling frame over two pulleys to the fall block, and thence to the winding drum. The travelling motor drives an endless rope attached to the frame, running it in or out as required. A large pulley is fixed at the outer end of the girder to take this rope. The capacity is 15 cwt., and the lifting is done with 10 B.H.P., at 100 ft. per minute, and the travelling with 1½ B.H.P., at 120 ft. per minute. These jiggers are made to be controlled from each floor, and also from two places on each floor, namely, one inside and one on a platform outside. The various points of working are interlocked in such a manner that the controllers can only be worked from one point at once. This is done mechanically by gearwheels and clutches, the various points being coupled by wire ropes driving small shafts with bevel wheels, and finally driving two controllers.

All these machines, with the exception of the jiggers, are driven by universal controllers, the general arrangement of which is shown in Fig. 9, and a diagram of connections for one motion is shown in Fig. 10. The resistances are all enclosed in special iron cases with radiating ribs, forming a compact arrangement easily fixed.

Machinery for Dealing with Traffic.—The capstans, which number forty-two, are designed for a pull of 1 ton, or six loaded wagons averaging a total weight of about 90 tons, at a speed of 250 ft. per minute. The motors are 26 B.H.P., and are compound wound, the series winding being on two poles and the shunt on the remaining two. The starting switches are operated directly by the treadle, a strong dashpot preventing too rapid movement of the switch. The switch also contains an overload release, which brings the switch to starting position and necessitates the treadle being released before the motor can be started again. This works very promptly, and prevents rough usage of the capstan. Whether this type of starting switch is the most desirable one for electric capstans is a debatable point. Electric capstans cannot be roughly treated as hydraulic capstans can. With the latter, if the capstan is overloaded (a very frequent occurrence), no harm is done to the capstan, and the load must be reduced until the power of the capstan is sufficient for the load before any movement will take place. Such methods of working cannot occur with an electric capstan, and unless a protective device is provided damage will occur to the apparatus. Provided the overload release is kept in order, the operator, however careless, will soon learn that the capstan must be treated with respect if any work is to be got out of it. Another serious objection to the direct operation of the starting switch by the treadle is that the necessity of gradually depressing the treadle tends to take the man's mind off his work, which is by no means without danger; also, owing to his having to work against the dashpot and balance weight attached to the treadle, he may not cut out all the resistance, which will burn out after a few such operations. The preferable method is for the treadle to operate a main switch only, the starting switch being automatically worked either by a magnetic coil or by gearing from the motor spindle. The movement of the treadle



FIG. 3.—Overhead Travelling Crane with Revolving Jib.





FIG. 6.—Overhead Travelling Jib Crane.





FIG 7.—Revolving Pillar Crane.





FIG. 6.—Overhead Travelling Jib Crane.

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FIG 7.—Revolving Pillar Crane.



FIG. 8.—Travelling Crab.

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then becomes a single one, as in hydraulic capstans. Another point which seems to be overlooked in capstans is the space allowed in the cast-iron tank. Capstans are often designed so small that it is impossible to get into them, and to make any repairs or alterations necessitates working in most awkward positions, where sight of what is being done is almost impossible. This is a great mistake. If the capstan is inside there is no reason why it should not be covered in by light plates, which can be easily removed and the whole of the

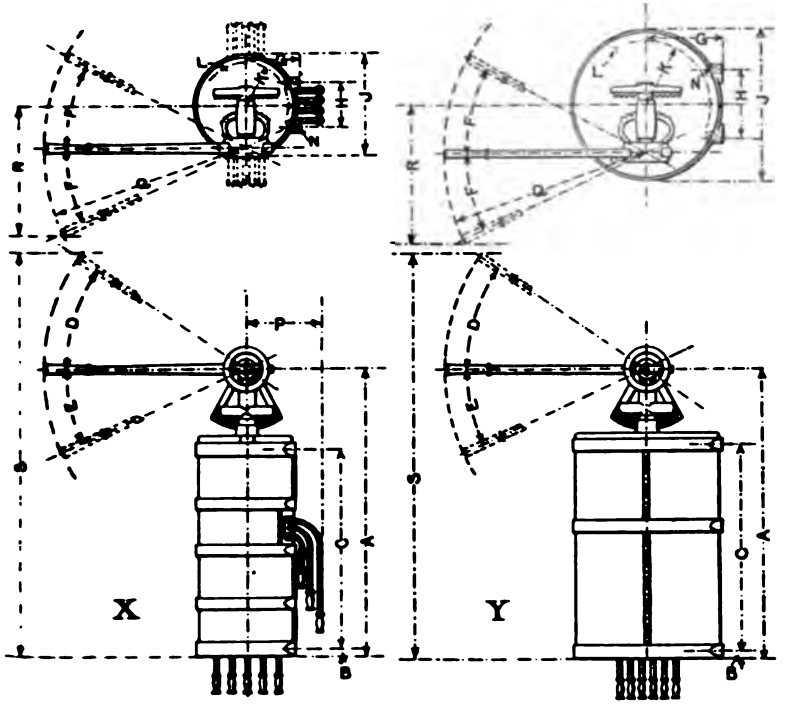


FIG. 9.—Universal Controller.

mechanism exposed. With outside capstans this would not apply, but the difficulty can be got over in a different manner. The author recently had the privilege of seeing several capstans in a goods yard in Lancashire which were excellently arranged. The tank was of a double pattern, fixed end to end, these ends being cut out to form a communication between the two. The tanks were very deep, and one of them was covered with a heavy lid in one piece, which carried the motor and the capstan head. The switchgear was also fixed in the same tank, and consisted of a double-pole switch worked from the treadle, a starting switch from the motor spindle, and a switch which

short-circuited the armature when the treadle was off, thus acting as a brake. The second tank was covered with light plates, and simply contained the outlet to the drain, and a ladder for descent. Access was easily gained to the capstan proper, and it was possible to pass in underneath the motor and capstan head and do any work required in comfort. All the apparatus was thus under a cover, which did not require to be removed, and there was room to deposit any parts which required to be taken down. Objection may be taken to the expense of having to dig a deeper hole for the tanks, but the advantages gained easily outweigh such objection.

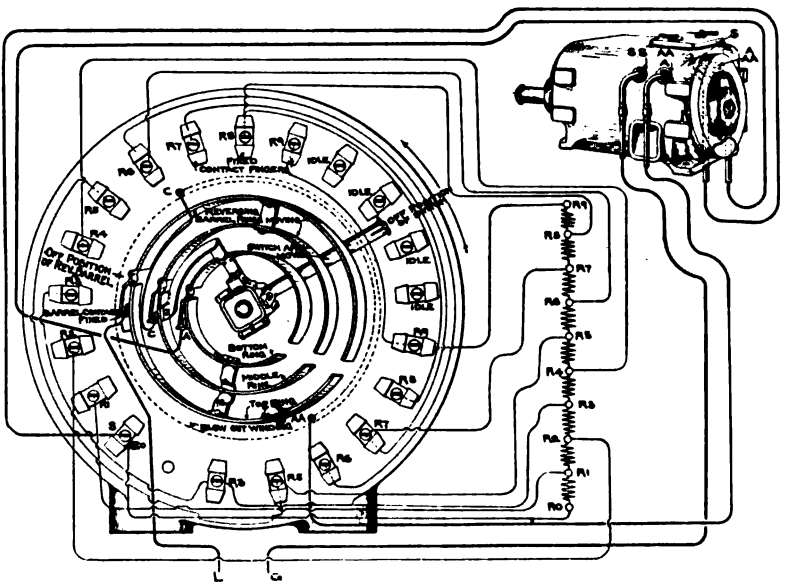


FIG. 10.—Connections of Controllers.

If all electric capstans were designed upon this principle it would do much to remove a number of the troubles which occur with electric capstans in practical working.

In the forty-two capstans at New Bridge Street the head is driven by bevel gearing, and the shaft of the armature is fitted with an electro-magnetic strap brake in series with the motor operated for braking by a heavy balance weight when the current is cut off. A view of the capstan is shown in Fig. 11, and a diagram of the connections of the controller in Fig. 12.

Wagon Hoists.—As will be seen from Fig. 5, the only access to the basement for railway wagons is by way of the wagon hoists. These are worked electrically, and are capable of lowering 30 tons and lifting



FIG. 11.—Electric Capstan.

20 tons. They are controlled on the push-button principle, and are probably the largest hoists of that type ever made. The hoisting arrangement is very simple, consisting, in reality, of two sets of huge pulley blocks. The usual method of operation is, however, reversed, and that block which is generally fixed is in this case the movable set, and the load is raised by means of the tail end rope. Its use in connection with a hoist, especially of such a size, is indeed very novel. The machinery, which is at the top of the hoist, is composed of two exactly similer parts, each driven by a 50-H.P. 240-volt compound motor, the motors being connected in series. Each motor is coupled to its gearing

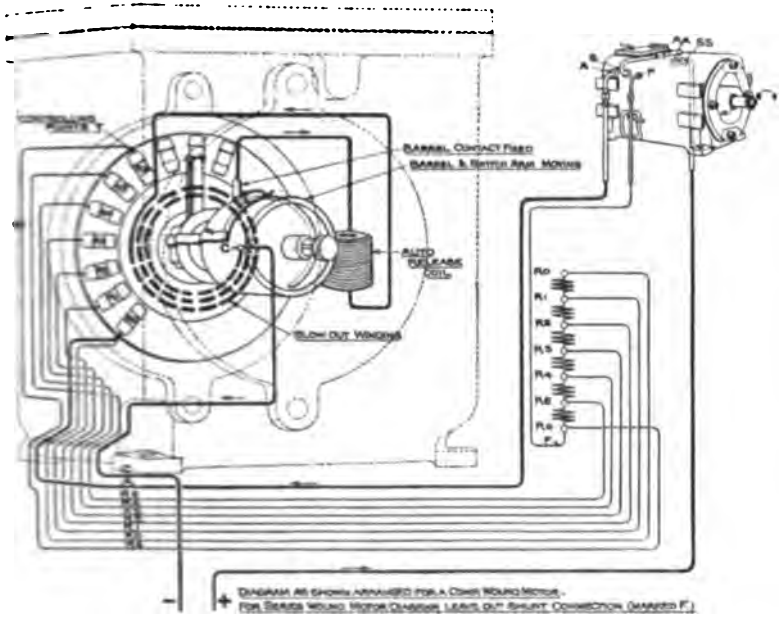


FIG. 12.—Capstan Controller.

by means of a shaft carrying a magnetic strap brake and also a high-speed centrifugal brake, to check too rapid motion. The gearing finally drives a large-toothed wheel, which has teeth over about ⅓ of its rim, the remaining part being simply flat. The two parts of the machinery are coupled together by means of a heavy crank-pin, forming a complete engine, and leaving a space of about 3 ft. 7 in. between the larged-toothed wheels, in which the ropes are operated. To this crank-pin are attached the ends of the four ropes which hoist the cage, and also the ends of the ropes connected with the balance weights which balance the load. Fig. 13 is a diagrammatic development of the method of attaching the ropes. Starting with the ends, the two

ropes are attached to the crank-pin. From thence they pass over a fixed pulley at the side (both ropes running in one groove). From this pulley they pass over the pulley on the crank-pin and back to a second fixed pulley, after which they pass over "dumping" pulleys to the top of the cage, the double rope opening out so that they may be attached to each side of the top beam. The ropes then return from the pulleys attached to the cage to the second set of blocks, finally

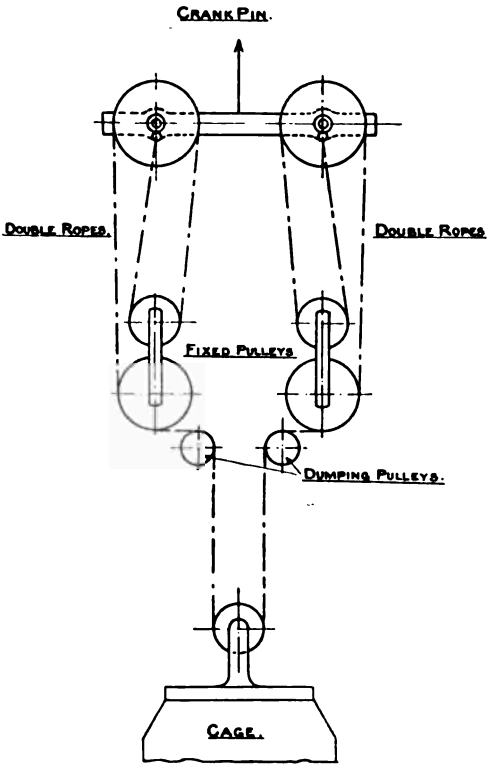


FIG. 13.—Diagram of Rope Attachments for Wagon Hoist.

being made off at the opposite end of the crank-pin to which they started. This arrangement is shown in Fig. 14. The switchgear is of Messrs. Smith and Stevens pattern, operated from push-buttons on the ground floor and from a set of push-buttons in the cage. Fig. 15 shows the connections and the various coils connected with the starting-gear, which is of the makers' usual pattern, enlarged to suit the size of the hoist.

The speed of the hoists is 60 ft. per minute and the lift 18 ft.

After the wagons are lowered to the basement floor they are received by a large traverser. This machine runs in a special pit 30 ft. wide and the full width of the building, as shown on Fig. 5. The traverser consists of a large platform 27 ft. long and 18 ft. wide, running on eight large grooved wheels on four sets of rails. There are also two sets of roller wheels running on the same rails to take the centre weight and that of the driving platform. Upon one side, which is extended and fitted with a hand-rail, is fixed the motor which drives the traverser, and also a capstan head for drawing wagons on to the traverser from the hoists. The motor is 26 B.H.P., driven by a simple reversing controller. The motor drives a shaft fitted with a double-

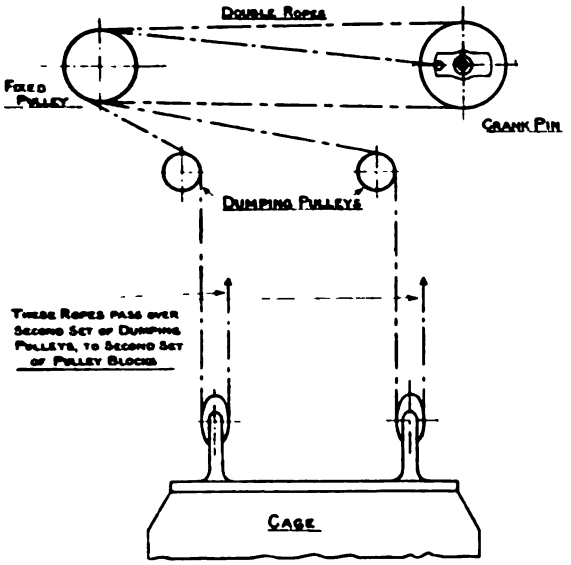


Fig. 14.—Diagram of Rope Attachments for Wagon Hoist.

clutch gear. One clutch drives the nearest shaft which carries the running wheels, and the other clutch drives the capstan head. The clutches are operated by one hand-wheel so that both motions cannot be used together. The clutch connecting the capstan head is arranged to drive the head in one direction, the reversal of the motor driving the shaft only, the arrangement being similar to that of a free-wheel. Current is carried to the motor through collectors fixed underneath the floor of the traverser and running in a conduit carrying the bare wires. The speed of the traverser is 300 ft. per minute, and the capstan speed 200 ft. per minute.

The power is taken from the Newcastle Electric Supply Company's Pandon Dene sub-station at a pressure of 480 volts between the outers.

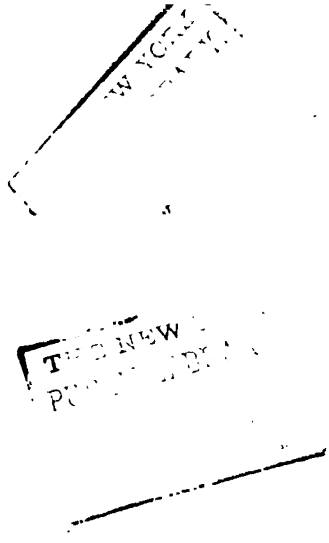
SCHEDULE OF POWER INSTALLED.
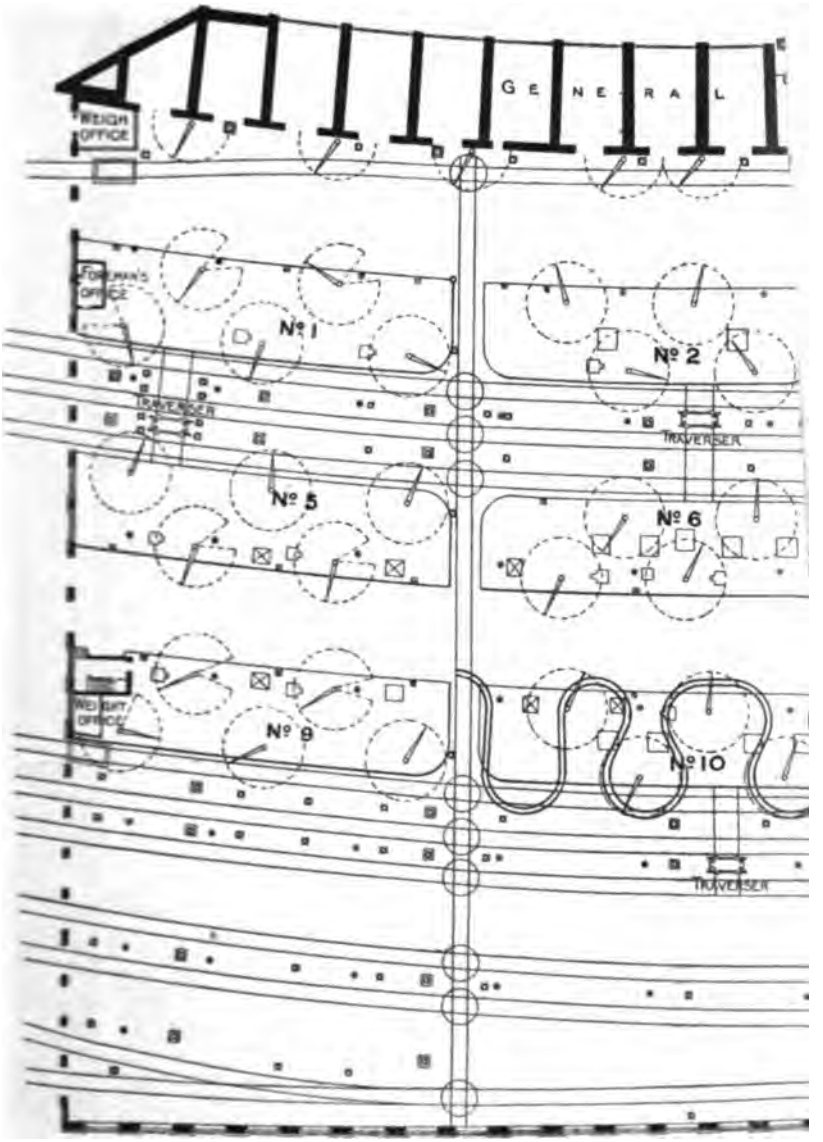
	No. of Machines.	No. of Motors.	Power of Machine, B.H.P.	Total Power, B.H.P.
Basement—				
Overhead Travellers ...	2	8	11¼	22·5
Revolving Pillar Cranes...	2	4	7½	15·0
Wagon Traverser... ...	1	1	26	26·0
Wagon Hoists	2	4	100	200·0
Capstans	16	16	26	416·0
Ground Floor—				
Travelling Cranes ...	4	16	23	92·0
Radial Wall Cranes ...	2	4	7½	15·0
Capstans	26	26	26	676·0
Second Floor—				
Transporters	2	4	16½	33·0
Jiggers	4	8	11½	46·0
Third Floor—				
Jiggers	2	4	11½	23·0
Total	—	—	—	1564·5

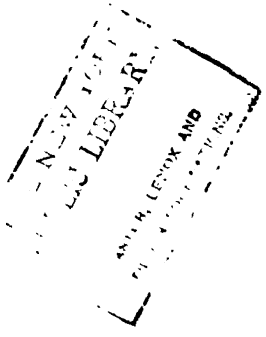
All the power is supplied at this pressure and the lighting at 240 volts. The whole building is controlled from two switchboards, one for power and the other for lighting, a separate account being kept of the energy used for each.

With regard to the cost of electrical working, the New Bridge Street Warehouse has not yet been in use to any large extent, so that no figures can be given. Some interesting figures are, however, given below with respect to a goods warehouse in the South-West of England. This warehouse originally contained 50 hydraulic cranes and 6 hydraulic capstans. Before deciding to electrify the cranes, etc., experiments were made to ascertain which cranes and capstans used most of the water. It was found that three of the cranes, and the six capstans, used 90 per cent. of the water. It was then decided to electrify these and drive the remaining cranes with electrically driven pumps. The cranes were electrified by fixing a lifting and slewing gear on a fixed framework underneath the bench, utilising the old crane posts and jibs. In one case the old hydraulic controllers were used to work liquid starters, in the second crane special liquid starters were fixed, and in the third crane, which was used most frequently, ordinary controllers with wire resistances were used. The two pumps were fitted with 15-B.H.P. motors and worked automatically from

Brake switch
Brake switch
Series lead
Shunt leads
Series
Shunt
Motor Nº1
Kicking coil Nº1.
Brake coil Nº 1.
Series lead.
Armature leads.
Series.
Shunt
Motor Nº2
Kicking coil Nº2
Brake coil Nº 2.




GENERAL
WEIGH OFFICE
FOREMAN'S OFFICE
No 1
No 2
TRAVERSER
TRAVERSER
No 5
No 6
WEIGHT OFFICE
No 9
No 10
TRAVERSER
EXTENDED 1892


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float switches on the accumulators. By means of change-over switches in the float circuits, the pumps and accumulators could be grouped as desired. These alterations were carried out at a cost of £1,157, and the cost of working fell from £600 to £150 per annum. The saving of labour in such cases is very great, especially if the power is taken from a public supply as is done in the case mentioned, the rate being 1d. per unit.

This shows what a great saving can be made by means of electric driving even by converting steam or gas-driven hydraulic pumps to electrically driven pumps, and working these by automatic switches.

Under the heading of conversion of plant may be added a change which was made at the Forth Goods Warehouse, Newcastle. Referring to Fig. 16, it will be seen that upon the benches are a number of plain squares. These are hatchways for the cellars, and the hydraulic cranes are arranged so that most of them can lower material into the cellars. It was decided to experiment on one row of benches with electric cranes. A crane of the transporter type was designed, and the track laid out in such a manner as to pass over the roadway, benches, and railroad, and at the same time to pass vertically above the principal hatchways. This necessitated the specially shaped track shown on Fig. 16. The track is made of channel iron and carried on a series of lattice girders attached to the roof columns. Current is conveyed to the motors on the transporter through the track rails, which necessitates the insulating of each support. Some difficulty was experienced with this at the commencement, due to the vibration breaking down the insulated bolts. This trouble was easily got over by using hard red fibre plates, and bushing the holes with two fibre tubes and washers, one tube sliding within the other. This made an excellent joint, and no trouble was experienced afterwards. The transporter consists of a small bogie running on four wheels and driven by a vertical motor fixed on top of the framework. To the underside of this framework are attached the cage and lifting gear. As there is a difference of 480 volts between the rails, the wheels have to be insulated from the axles. Brushes press on each wheel and carry the current to the motors and the controller, which is of the universal type previously described. The lifting capacity is 1 ton, and the lifting is done with a 15-B.H.P. motor, the travelling motor being 3 B.H.P.

There are two transporters on the track, and these displaced eleven hydraulic cranes. They work very well and can easily perform the duties which were previously done by the hydraulic cranes. The number of units registered against these cranes averages 350 per month, which is very small, and if the wages of the boys who drive the cranes are added the total cost taken at the power rate of most supply companies would be insignificant compared with that of the number of hydraulic cranes displaced.

ELECTRIC POWER IN DOCKS.

By C. E. TAYLOR, Associate Member.

(*Paper received from the* NEWCASTLE LOCAL SECTION, *November* 22, 1907, *read at London on February* 20, *and at Newcastle on February* 24, 1908.)

During recent years the use of electricity for power purposes in docks has been greatly extended, and as the power companies, now feeling their way, develop their business, it is probable that a still greater extension will take place. Electricity offers many advantages over the hydraulic system (which has up to recent times held this field almost exclusively), especially in places where electric power can be obtained at a reasonable rate from an outside source, and the user has not to incur the heavy capital expenditure involved in the provision of a generating station for the exclusive supply to the dock premises above. It is generally admitted that, where a reliable supply can be obtained from an outside source, as in the Tyne district, it is much more advantageous to take supply from that source than to generate for such loads as are obtained in docks where the total consumption is small and the maximum demand large.

From the users point of view the advantages are great. The installation cost for distribution is small compared with that for a hydraulic supply, and not so liable to failure, whilst the consumption is proportional to the work done. The efficiency of electric machinery is necessarily much higher than that of hydraulic plant for the same purpose, especially that of the older type, and the distribution is more flexible and lends itself to alterations and additions as they become requisite much more readily than its competitor.

The uses to which electrical machinery has been put in dock workings are numerous and are continually extending. For the loading of general merchandise the high gantry crane is much used, for short-distance electric traction capstans are very much in evidence, and for coaling vessels electric cranes and hoists are used, the former where the better facilities afforded by jetties or staiths cannot be arranged. Electric power is used also for preventing the breakage of coal which takes place when run from considerable heights into the holds of vessels, and it has recently been used to obviate in a simple and inexpensive manner, the necessity for alterations to existing staiths and jetties, which the increasing size of ships employed in the coal trade would otherwise involve. In other cases it is found that, whilst not desirable to replace all hydraulic by electric plant, it was advisable to make a

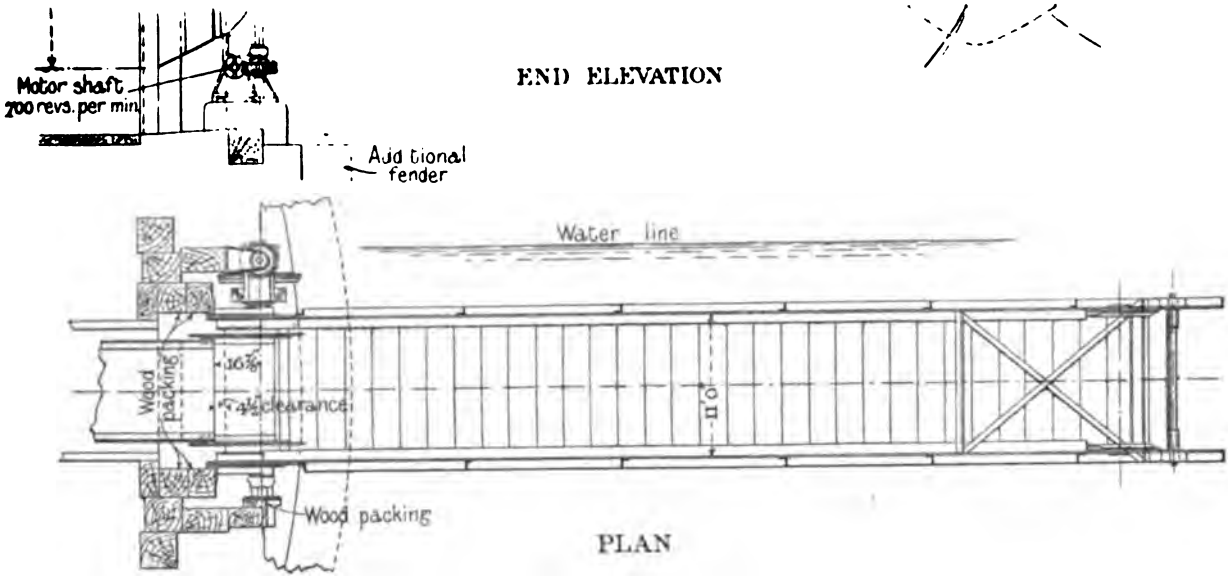


FIG. 1.—Motor-driven Coal Conveyor. Tyne Dock.

beginning on a settled policy. Such a case may be instanced as that at the North-Eastern Railway Company's Dock—Tyne Dock—where the steam pumping plant, being old, is being replaced by electrically driven pumps with the intention of gradually replacing the hydraulic cranes, etc., as necessity arises, by electric plant also.

Coal Conveyors.—The difficulty of loading bunker coals into vessels when light from the older jetties or staiths has led to the adoption of special apparatus capable of running the coals on the level or on an inclined plane. One form of this apparatus is shown in Fig. 1. Coal conveyers have recently been brought into use at the North-Eastern Railway's Company's Dock at Tyne Dock. The arrangement consists essentially in making the spout into an endless belt conveyor, coals being shipped at low level, and run over the belt in the ordinary way. When shipped into vessels, level with the spout, or above it, the latter is adjusted as may be required, and the belt run by an electric motor, the coals being carried along until they reach the hatch, when they drop over into the hold. The belt spout can be adjusted to any angle, but the useful maximum is about 25°, and at this angle some 500 tons can be shipped by each conveyor per hour. Some experiments have recently been made on these conveyors, and it was found that the average power working at full load on a slight inclination was 12 H.P., and the consumption during the test was 7 units, with a total quantity of coal shipped, equal to 410 tons, giving an average per ton of over 17 unit. Whilst the test was in operation some further experiments to show the power absorbed with various inclinations of the belt were made, with the curious result of a constant absorption of power for any inclination was obtained. Practically the power remained constant at 12 H.P., and it was found that the belt automatically regulated the quantity of coal carried according to the inclination. This was a result that had never been anticipated.

A 3-phase motor, capable of developing 16 B.H.P. at a speed of about 800 revs. per minute, drives the spout by a suitable reduction gear at a velocity of 120 ft. per minute. A margin between the average absorbed, and the total power of which it is capable, is allowed for cases where the belt is required to start with a considerable amount of coal upon it, or to take the load if coal is dumped upon it very freely, as often happens.

The arrangement is extremely efficient for the purpose for which it is intended; no other motive power could have been used in this case, and the adoption of the system has obviated the necessity for reconstruction of the staiths for a very considerable time. In this way there has been a great saving on capital expenditure.

Anti-coal-breaker.—The more modern staiths for shipping coal at North Blyth have shown another defect which the use of electric power has done much to remedy. The staiths are very high and coal has a long way to drop into the holds at low tide, with the result that much coal is broken, and its value is diminished thereby.

The anti-coal-breaker arrangement consists essentially of a system

of buckets balanced to run over the suspended shaft, the whole being suspended from the jib of an electric crane fixed on the upper part of the staith. Coal from the ordinary spout is run into the buckets on one

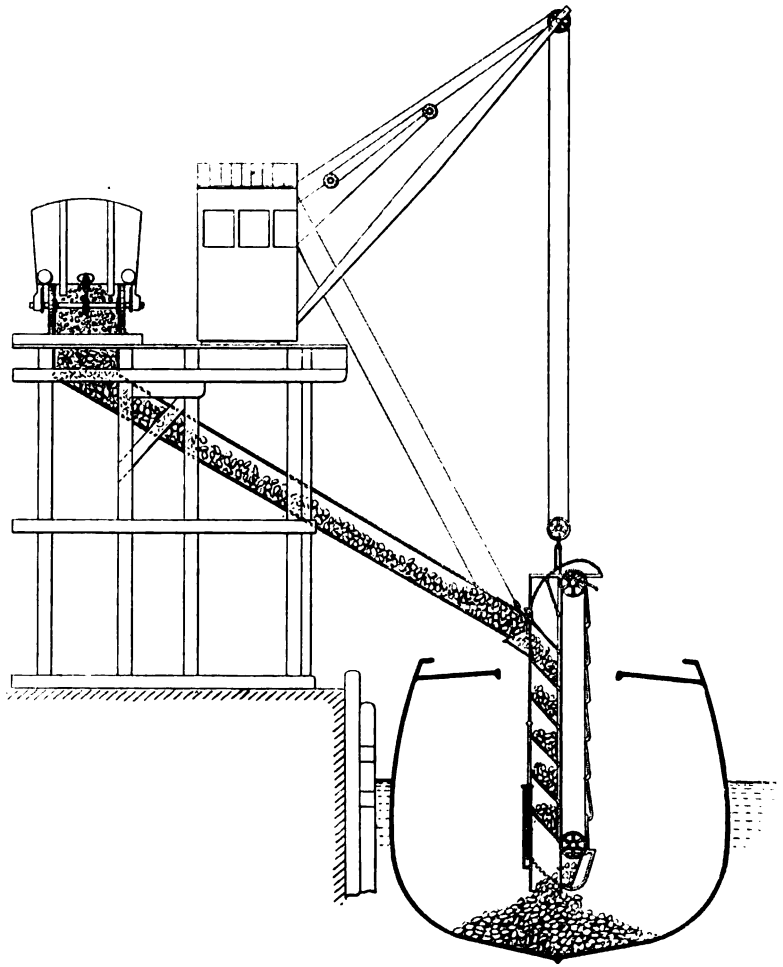


FIG. 2.—Sectional View of Anti-coal-breaker, showing Method of Operation.

side of the chain, and these are carried by gravity into the hold of the vessel, where they are emptied and the buckets begin the return movement. The whole arrangement is clearly shown by Fig. 2. The jib crane is capable of carrying 8½ tons, and the lifting and slewing motors are 20 and 8 B.H.P. respectively.

The lifting speed is 25 ft. per minute. As will be seen from Fig. 3, the speed of the bucket chain is capable of being regulated by an automatic centrifugal brake to a velocity of 120 ft. per minute.

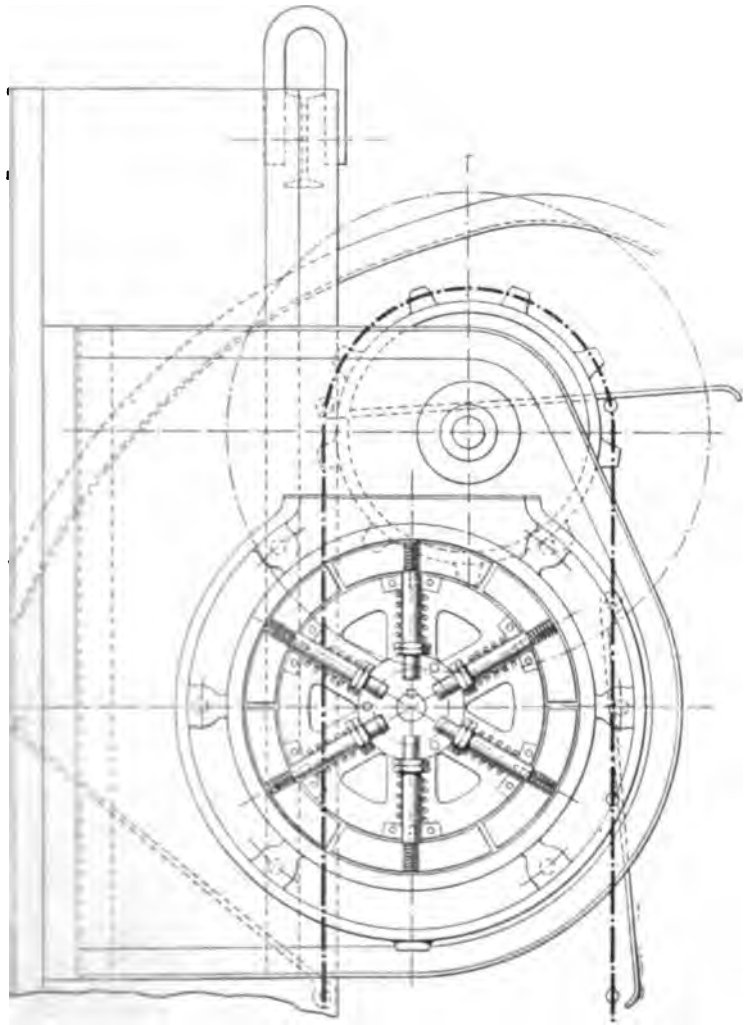


FIG. 3.—Centrifugal Friction Brake for Controlling Automatically Speed of Anti-coal Breaker.

Coal Hoists.—In cases where the ground-level is low, coal hoists are used to a great extent and also coaling jib cranes.

With regard to coal hoists this is a field in which hydraulic

machinery has hitherto been universally adopted. The wagons are raised by a hoist and tipped by means of another ram attached to the platform, the wagons being fitted with end doors; the wagon is then lowered again and the platform lowered to a high-level empty wagon road, where the wagon is run off and the platform lowered to the ground-level for another full wagon.

Electrically driven coal hoists, which perform exactly the same operations, have recently been erected at Rothesay Dock, Clydebank, by the Clyde Navigation Trustees.

In some cases coaling cranes are displacing hoists, or are being

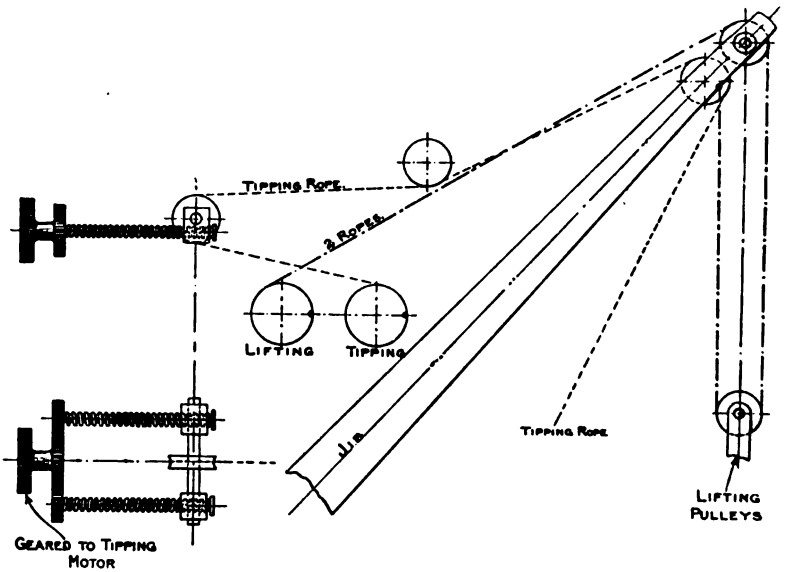


FIG. 4.—Diagram showing the Arrangement of Lifting and Tipping Ropes for 85-ton Electric Cooling Crane.

provided as additions. A typical example is the 25-ton crane installed on Humber Dock Quay, Hull.

The lifting is done by two 50-B.H.P. motors, both coupled to the same shaft, and controlled by a series parallel controller—the tipping motor is 50 B.H.P. and the slewing motor 20 H.P. Fig. 4 shows the arrangement of the ropes for lifting and tipping the wagons, the slack of the tipping rope is taken up by another barrel, which is geared to the lifting barrel, the rope being taken over a pulley which is fixed to two square thread screws. These screws are driven by the tipping motor and draw the pulley backwards and forwards, thus effecting the tipping motion.

The radius of this crane is 31 ft., the height of jib from road-level is

50 ft., and the approximate amount of coal which can be shipped by this crane is 230 tons per hour.

Wharf Cranes.—For loading and unloading material of a general kind and iron ore, etc., cranes of a high gantry type are in universal use. These cranes take up a minimum amount of space on the quay, and allow wagons, etc., to pass under them. In cases where a warehouse is built on the quay, a slight alteration is made by having one side of the gantry running on the quay wall, and the other running on a girder let in to the building. This still enables wagons to pass under the cranes as before.

Cranes of the high gantry type are in use at various docks, those at Middlesbro' and Hartlepool, on the North-Eastern Railway Company, being capable of lifting 10 tons and 3 tons at 150 ft. per minute, 1½ tons at 250 ft. per minute, and slewing at 400 ft. per minute.

The jib radius is 45 ft., and the height of the jib top from the quay-level is 60 ft. The hoisting gear is driven by a 50-H.P. motor at 300 revs. per minute, and is geared direct to the barrel. On the motor shaft is fixed a band brake operated by a special electromagnet in series with the armature of the lifting motor. The two poles of the magnet are similar to a small 2-pole dynamo with upright poles, and revolving between them is a solid steel armature, connected by a lever to the brake which is held on normally by weight.

When the fields are excited and motor is started this armature turns through 90° and raises the weight, thus releasing the strap. The brake can also be operated by a lever near the controller, so that lowering can be carried out without the power being applied to release the brake. The slewing-gear is driven by an 8-B.H.P. motor at 1,000 revs. per minute, coupled to which is a worm driving a worm-wheel. This gears with a spur-wheel on a vertical shaft, carrying the driving pinion which engages with a circular rack fixed on the top of the gantry.

The motor is controlled by a foot brake on the motor spindle. The cranes revolve on twenty-four cast steel rollers. A universal controller is used for both motors.

The collector gear is fixed to a pillar in the centre and cables pass up the centre column and are attached to two rings mounted on ambroin, upon which are brushes fixed on porcelain insulators attached to the cabin floor, and from which wires pass to the controller.

The cranes are moved along the quay wall by a 4-B.H.P. motor at 30 ft. per minute, the gearing being arranged for hand working if necessary, each side being driven by means of a cross-shaft and bevel wheels. Current is taken from underground mains on the quay which are connected at intervals of 50 ft. to plug boxes. The crane plug is bell-shaped, to prevent water entering the boxes whilst the cranes are in use, and can only be attached in one way, so that the correct motion is obtained.

The 10-ton cranes are of the same design as the 3-ton cranes. The lifting motor is 60 B.H.P., and the revolving motor is 12 B.H.P.

The lifting motor in single gear drives directly through a pinion on to the barrel, the ratio being 8 to 1, and a double part of rope is used. With single gear loads up to 2 tons are lifted, and double gear is provided for loads over 2 and up to 10 tons.

It will be seen that in these cranes when lowering the motor is driven by the weight, but a new device is now in vogue on similar cranes, patented by Messrs. Stothert & Pitt. The lifting barrel is not keyed directly to the shaft, but runs loose on it, and is connected or disconnected by a friction clutch. The barrel shaft carries the main spur-wheel rigidly keyed on to it, and this spur-wheel gears directly by single reduction with the pinion attached to the armature spindle of the lifting motor. The hand lever actuating the lifting controller, also actuates an electric solenoid which controls the lifting friction coil clutch, the arrangement being such that on moving the lifting handle forward from the off position, current is switched on to the solenoid, the clutch is put into gear, and the lifting motor started simultaneously; after the clutch is in gear a further movement of the lever cuts out resistance and speeds up the motor. Provision is also made of a mechanical connection between the lifting controller handle and the coil friction clutch as an alternative to the electric solenoid. A large friction brake drum is keyed directly on to the lifting barrel, the brake strap being lined with willow blocks. The lifting controller does not reverse the motor, as the lowering is carried out independently by the loose drum.

The great advantage of this arrangement is the large increase in speed of working both in lifting and lowering, and also the reduced liability of accident to the motors, owing to the impossibility of suddenly stopping the armature.

In cranes with the barrels always in gear with a reversible motor, care has to be taken to check the lifting motor when the hook is a sufficient distance from the jib head, so that the momentum of the revolving armature may be absorbed before the hook is overwound on the jib pulley, with the possible result that the jib itself is lifted and the tie rods bent. With the system described above, lifting can be continued at full speed and the load brought to rest instantly by pulling over the handle, the only revolving parts which have to be brought to rest being the barrel and brake drum, which have comparatively small inertia and do not revolve at an excessive speed. The great gain in speed is in lowering, which can be performed at a vastly greater speed than is possible by a reversible motor, there being a perfectly free run out under the control of the foot brake, and what is of equal importance, lowering can be commenced instantly without perceptible pause from lifting at full speed; the lifting armature can continue to revolve with slackening speed during the period of lowering, and then comes to rest quietly without shock. As a matter of practice it is found that a load can be lowered 60 ft. before the armature has ceased to revolve.

Capstans.—It is unnecessary to deal fully with capstans as these are

well known, but at Rothesay Dock a special capstan has been designed by Messrs. Baxter & Dixon, of the Clyde Navigation Trust, in which the principal feature is a fixed rope and loose head. A wire rope is permanently fixed to the capstan head, which is made to run loose on the spindle, but when required is connected to the spindle by a clutch sliding upon the upper end of the spindle inside the capstan head.

The starting switch and clutch are controlled by a long lever which in the backward position releases the head by throwing out the clutch and in the other direction puts in the clutch and operates the starting

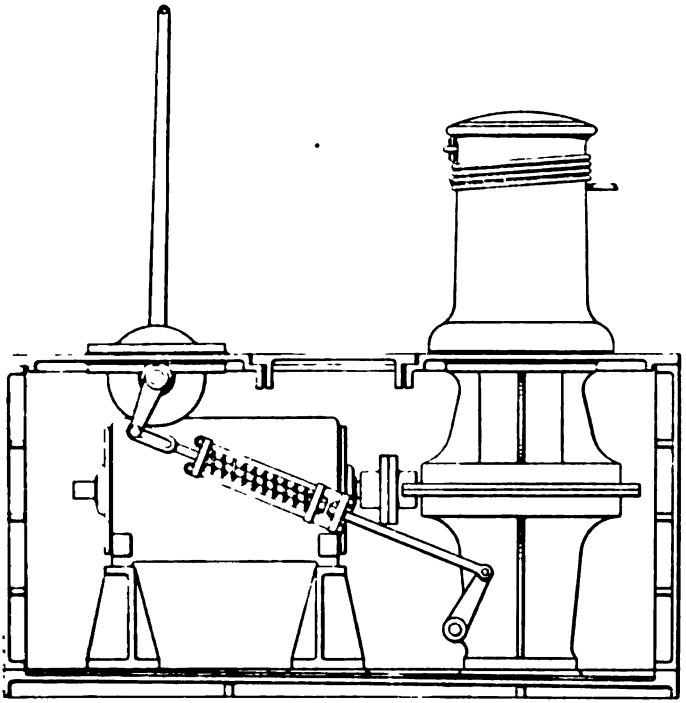


FIG. 5.—Type of Capstan with Fixed Rope and Loose Head.

switch. The man is thus free to work his starting switch in an upright position and see all that is going on, as against one foot and two hands. In places where a number of wagons have to be drawn up and used one at a time as in a coal hoist, this is a very good arrangement, as there is a great saving in ropes and no wear on the capstan head. This type of capstan is shown by Fig. 5. The saving effected by electric capstans is sometimes very large, and in some cases where they have displaced steam engines on staiths, which were previously necessary in order to run the wagons to the spouts through cross-over roads, etc.

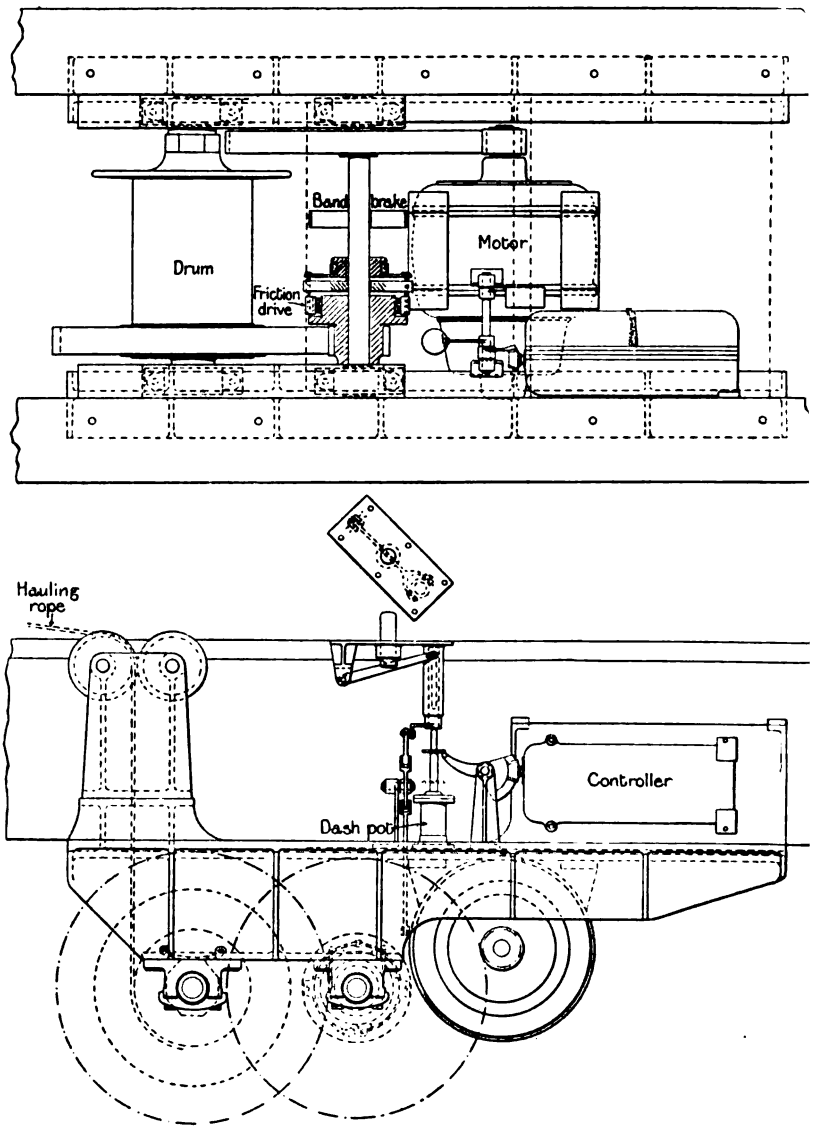


FIG. 6.—Under-deck Type Capstan.

Electric capstans can be fitted in many cases where other forms could not be used. On the North-Eastern Railway Company's staiths at Dunston an under-deck type of capstan fixed entirely under the floor of the staiths is being experimented with. In this case the capstan is not furnished with the usual head, the rope being carried round a horizontal drum. This type of capstan is shown by Fig. 6. The motor is a 30-B.H.P. 3-phase motor, running at 770 revs. on a circuit of 440 volts 40 ∿, and drives by means of a pinion a first shaft which has fixed upon it a friction drive for operating the barrel shaft. The barrel has on it a fixed rope which passes over the horizontal drums placed level with the floor of the staiths, so that the rope may work in either direction as required for hauling purposes.

The method of working is such that, when the treadle is depressed, the stator is made alive, and the motor brought up to speed by cutting resistance out of rotor circuit; at the same time the band brake is released, the friction clutch engages with its drum, and the rope is wound round the barrel.

When the treadle is released the clutch allows the rope barrel to stop immediately, and the momentum of the motor is pulled up gradually by the band brake. This is a very essential point, as the wagons are drawn down a slight decline over the cross-over roads to the spouts, and each wagon must be stopped immediately over them; otherwise, if they run past, the whole train of wagons must be hauled back up the gradient.

The motor is only operated in one direction, the drum running freely when slack rope is needed, which is drawn off by hand as required according to the number of wagons to be hauled.

Electric-driven Hydraulic Pumping Plant.—Any new dock which may be built would probably be fitted with electrical power throughout, as at Rothesay Dock, Fishguard, etc., but it cannot be expected that the hydraulic plant in use at an old dock should be pulled out and replaced by electrically driven machinery until worn out.

An improvement can, however, be made by installing electrically driven hydraulic pumps supplied by power from a power company and working these automatically. This method does away with all boiler-house expenses, leaving practically only the engine-room staff to operate the pumps.

A change of this kind is at present being made at Tyne Dock, where three engines and five boilers are being replaced by four electrically driven pumps with 3-phase motors of 132 B.H.P. each. These drive 3-throw crank pumps through a flexible coupling. Each motor is provided with a 3-phase automatic starting switch driven by a small motor $\frac{1}{17}$ H.P., which is connected between two of the phases and brought into action by a switch attached to the accumulator.

Fig. 7 shows a full diagram of connections for this starting switch, the method of working being as follows:—

Each automatic switch is connected to the mains through a 3-pole switch M, which has a no-voltage release and is fixed on a separate

switchboard. From this switch one main passes direct to the motor, whilst the other two pass through a magnetic blow-out switch fixed to the auto-starter, and operated by cam X. The circuit for working the auxiliary motor is coupled to two phases on the live side of switch M.

Current passes along wire N, through overload relay, to cams marked W_1, W_2, W_3, which make and break contact with points 1, 4, and 3 as

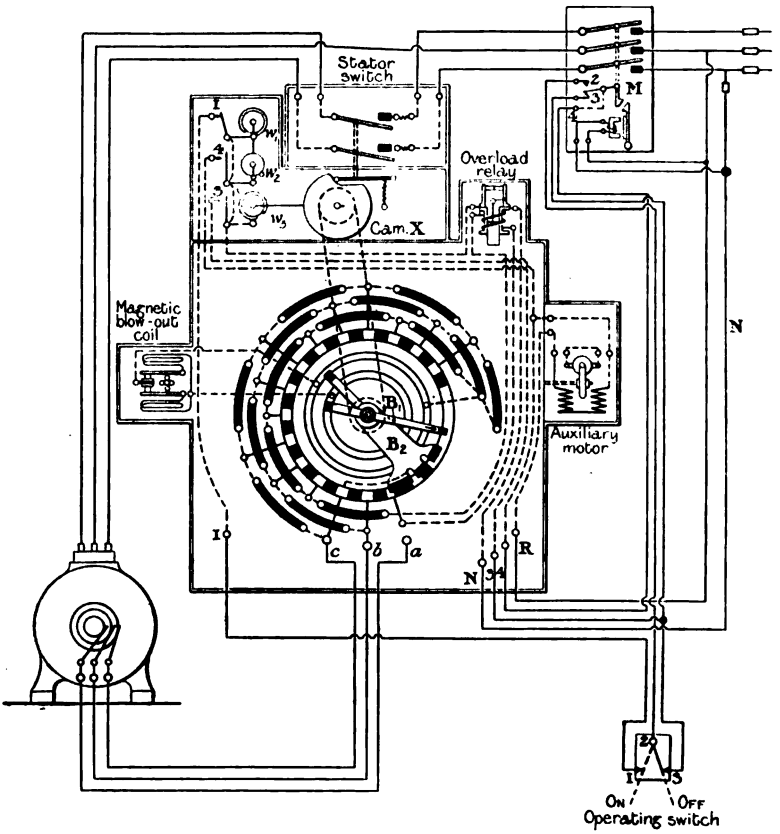


FIG. 7.—Automatic 3-phase Starting Switch. Diagram of Connections.

required. In starting, current passes down No. 1 to the operating switch on the accumulator, and as the accumulator is down passes to No. 2 on the switch, across to No. 4 on switch M, from this point to No. 4 on the starting switch through the auxiliary motor, and on to the other phase. The auxiliary motor now runs and drives the rotor switch, cam X, and cams W_1, W_2, W_3.

This closes stator switch and No. 4 wire by cam W_2, No. 1 is then opened by cam W_1, the auxiliary motor continues to run through No. 4

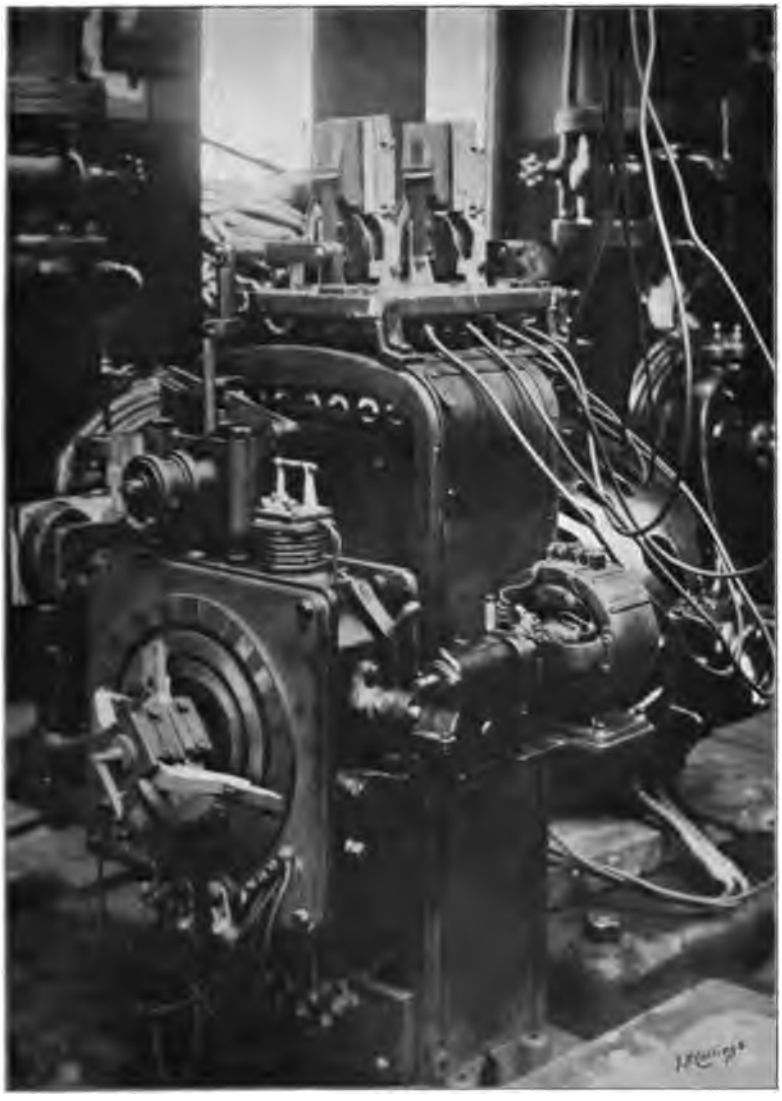


FIG. 8. —3-phase Automatic Starting Switch, showing Arrangement of Auxiliary Motor and Overload Relay.

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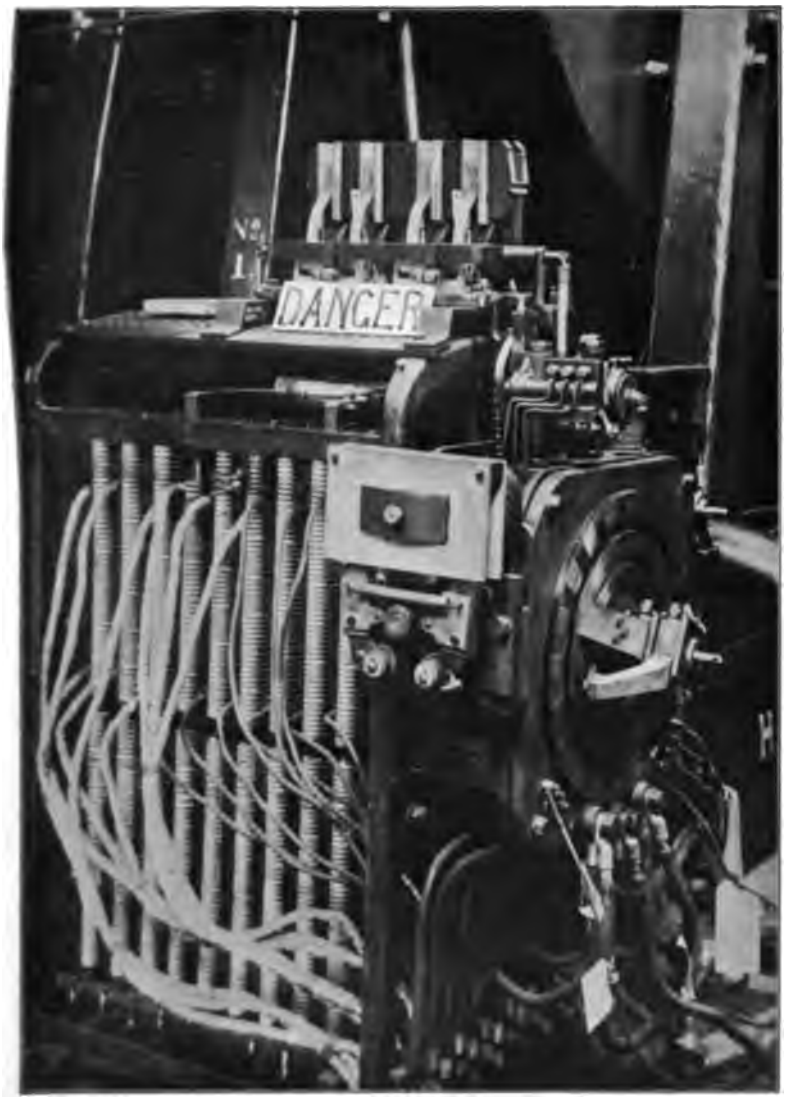
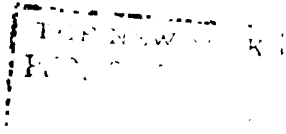


Fig. 9.—3-phase Automatic Starting Switch, showing Position of Magnetic Blow-out for Rotor Circuit Switch.



wire contact until all resistance is cut out of rotor circuit, when cam W_1 opens contact No. 4 and puts in contact No. 3. This operation stops the auxiliary motor until the pump raises the accumulator sufficiently high to change over the operating switch to the off position, thus putting the auxiliary motor again into circuit and revolving the rotor switch to the off position, and opens the stator switch by cam X. On switch M is a contact No. 3, which is used, in case of failure of supply, to prevent damage when supply is resumed. When supply fails, switch M opens, putting contacts 3 and 4 in connection with each other; thus, when the power is again put on, current can pass to the auxiliary motor by way of cam W_3, through 3 and 4 on switch M to auxiliary motor, revolving automatic switch to the off position immediately, and preventing switch M being closed with all resistance out.

Between arms B_1 and B_2 is coupled an automatic magnetic blow-out coil which is opened and closed in conjunction with the automatic switch to prevent sparking on the rotor switch. Figs. 8 and 9 show different views of this automatic switch.

Other machinery at this power station comprises two centrifugal pumps driven by 8-B.H.P. motors, which are operated by similar starting switches. These pumps are used for pumping the return water from a well at the lowest point of the dock up into tanks near the accumulators.

Discussion in London.

Mr. Roger T. Smith: I think both of these papers are most interesting, not only to electrical engineers, but to railway men, as showing the amount of electrical working of railway apparatus that is being carried on by one progressive company. There is only time to refer to a few of the many interesting points in the papers. I should like first to draw attention to the lifting speeds of the various cranes referred to in the first paper. The underhung revolving jib crane at New Bridge Street hoists at 150 ft. per minute, and the height of the hook above the rail is about 20 ft., so that it cannot lift a load more than about 12 ft. That means that 1 ton is lifted at that speed in rather less than 5 seconds. As the average load would be something like ½ ton, it appears to me that this is very much too fast, and that the motor would always be running on its resistance, and would never get on to its own proper curve. Probably the speed should be 50 ft. per minute instead of 150 ft., and in that case the motor could have been reduced from 15 H.P. to 6 H.P. The travelling hoists at New Bridge Street, which lift from the rail to the roof, hoist 1 ton 70 ft. at 150 ft. per minute. That means that 1 ton is lifted in about 28 seconds. This would seem to be slow, and it would have been better if the speed had been 200 or even 250 ft. per minute instead of 150 ft. per minute. The jiggers described at New Bridge Street, also lifting from rail to roof, hoist ½ ton 70 ft. at 100 ft. per minute. That means that ½ ton is lifted in about 40 or 42 seconds. This might very

Mr. Smith.

Mr. Smith. well have been 200 ft. per minute; and I should like to ask the author if the apparatus was re-specified whether these lifting speeds would not be altered with advantage. The travelling and traverser speeds appear to me to be good.

The underhung jib travelling type of crane described in this paper and the travelling hoists seem excellent arrangements. Imitation is the sincerest form of flattery, and after reading this paper it was arranged that Great Western officers should go with me to Newcastle to see the New Bridge Street machinery. The result is that the underhung travelling jib crane is now being specified for a new goods station on the Great Western Railway.

Another very excellent arrangement is the interlocking provided for the jigger lift controllers at this warehouse. As described, it is entirely mechanical and quite satisfactory. Passing to another point, I should like to refer generally to the design of electric capstans. In the first place, the capstans described pull 1 ton at 250 ft. per minute, and allowing about 85 per cent. efficiency for the gearing, the B.H.P. would work out at 20. The B.H.P. is stated to be 26, and I wish to ask the author if the reason for having such a much larger rated capacity than seems necessary is due to the fact that the motor is a compound-wound motor. The author has given some very interesting particulars as to his ideals of an electric capstan. With most of them I agree, but I would go a little further. I would say, in the first place, that as sweating is absolutely inevitable in a capstan (the first function of the capstan box as constructed being apparently to sweat), all fine wire coils should be done away with, and the gear driven by a series motor. Increased torque with decreased speed in the series motor is what is wanted for capstan working. Then, secondly, I quite agree that the treadle should only close a main switch opened by a spring or counterweight, and the switch apparatus shown working seems to me to be admirable in every respect. Then there must be some sort of resistance in series with the motor, and that should, in my view, be cut out quite independently of the switch, either mechanically or electrically, but preferably mechanically. Then a brake is required to prevent the series motor running away when it is unloaded, which might be put on either electrically or mechanically, but preferably mechanically, possibly by such an apparatus as described in Mr. Taylor's paper, where the anti-coal-breaking buckets are controlled by a centrifugal brake. Then the capstan head should be driven direct by worm-gearing, the worm being cut at such a low angle (less than 10°) that the capstan head tends to pull itself up. If possible the overload circuit breakers should be outside the box altogether, so that when they open they can be reset easily by hand. This is not, of course, always possible where cables are laid underground; but if, as in many cases in railway work, the cables are overhead, the circuit breakers can easily be put on the posts. Then, lastly, I should like an electric heater inside every capstan box, with proper ventilation holes, the whole of the inside of the box and cover being lagged so as to prevent sweating as far as

possible. The author described in a very few words a most interesting runway in the Forth Banks warehouse, which serpentines in and out, and that was to me so interesting that I went to Newcastle to see it, because I believe that the travelling underhung jib cranes of the sort described in this paper and runways, with travelling pulley blocks, are going to oust the fixed jib crane altogether from goods warehouses and stations. I cannot, however, congratulate the author on the electrical arrangement of that runway. The whole of the lattice work is alive, and it appears to me to be an arrangement similar to one in which if a tramway were being carried across a bridge the whole of the bridge were to be electrified and electricity collected from the top booms. I do not think that is either necessary or advisable. Then a very magnificent wagon hoist was shown and described. It is an ingenious and very fine piece of apparatus; but would it not have been far simpler and cheaper to have had a flat or troughed band conveyor from the top level down to the bottom—the process being to unload the goods on to the conveyor and run them into the warehouse underneath, instead of going to the expense of lifting and lowering the wagon weight as well? Mr. Smith.

Turning to Mr. Taylor's paper for a few minutes, the description of the Tyne Dock coal conveyor is, I think, a striking tribute to the economy of conveying as opposed to shipping by jib cranes or tipping hoists. Quoting from the paper, to ship 500 tons of coal per hour requires the continuous use of a 16-B.H.P. motor running at an average output of 12 B.H.P., that is, 500 tons per hour for 16 B.H.P. installed. From the description of the hoisting, lifting, and tipping cranes, 230 tons per hour are lifted and tipped, requiring the intermittent use of 120 B.H.P. in two motors. With about eight times the amount of power installed less than half the amount of coal is delivered. I have worked out the brake horse-power required in two of the most modern tips in the Alexandra Dock, South Wales, using hydraulic power. They deal with 400 tons of coal per hour, and require 50 B.H.P. at the tipping and about 100 I.H.P. in the pumping station. This shows, and the paper points out, what an economy there is in capital cost in the use of conveyors for dealing with coal, and the working costs are also so economical that I am very sure that before long conveyors for shipping coal into vessels will be used to a much larger extent than at present. The enormous maximum power required for cranes is a very important point where a dock has its own generating station, the load factor of cranes being very bad. At the Fishguard Harbour, referred to by the author, during last year the annual load factor—that is, the amount of work done compared with the amount which could be done by the plant installed (excluding spares) working at full load during the whole of the year—comes out at 9 per cent. for both lighting and power, and the annual load factor for eleven cranes alone to only 5·3 per cent. The conveyor described would probably have an annual load factor of something near 30 per cent., and the difference in the economy of working in this way can very well be imagined. There

Mr. Smith. are one or two questions I should like to ask the author, if there is still time. One is with regard to the material of the belt used in the conveyor. It looks from the drawing as if it were a series of plates, but I think the speed is put down as 100 ft. per minute, and that seems rather fast for a plate belt to run. I should like to know whether it is a plate belt or whether it is a rubber belt. Then I also wish to ask whether, in the anti-coal-breaking arrangement, there is any trouble with the centrifugal brake that controls the speed. I might also refer to the 3-phase electrically-driven centrifugal pumps just touched on by the author. I happened to be at the works where they were being tested before they were delivered to the North Eastern Railway. They are centrifugal pumps with a single impeller, but with a special arrangement by which eddy currents in the water are prevented and velocity reduced to pressure entirely outside the pump. The instantaneous efficiencies of those pumps come out at 80 per cent. I do not mean to say that they worked steadily at 80 per cent. efficiency, but it was occasionally reached. I believe that is the highest recorded efficiency for a single impeller pump, not being a turbine pump, that has ever been obtained.

Mr. Neele. Mr. C. W. NEELE: I should like to ask Mr. Henderson if there are any safety switches or circuit breakers provided in connection with these jib cranes to prevent overwinding. On the railway with which I am connected—the Great Central Railway—we have installed several electric cranes, and the great difficulty we have had with them is on account of their very small head-room or maximum lift. I do not know if these drawings are to scale, but if Fig. 4 is to scale the clearance between the jib and and the rail level gives only about 12 or 13 ft. head-room. The ordinary high-sided wagon is 7 ft. from the rail level to the top of the wagon side. Allowing 2 ft. for the weight and the hook, that leaves 3 or 4 ft. to take the load over the top of the wagon side, altogether independent of any chain slings, and it appears to me that cranes can be of very little use in that position. We have installed some cranes at our Liverpool warehouse which have a clearance of 18 ft. I provided safety switches to prevent overwinding, but we found these had to be done away with because we could not lift the load over the side of the wagon. These cranes have to handle very big packages, 4, 5, and sometimes 6 ft. in height, with the consequence that we were continually getting broken ropes. The crane boys in endeavouring to get the load on to the wagon used the jib of the crane as a lever to try and jerk or pull the load over the side of the wagon, with the result that we had broken teeth in the slewing rack, broken slewing racks, and even the shaft of the slewing pinion has sheared right off. The authorities in our goods department are asking for speeds of 100 ft. and over for lifting, even on these short lifts, and with a view to minimising the danger of overwinding I have been specifying in connection with some cranes we are about to instal, taper-winding barrels, so that the load can be lifted at the maximum speed at the commencement, and gradually decrease until when it gets close up to the top of

the lift it is at its minimum speed, so that the load may be more easily handled and "nursed" near the top of the lift. It seems to me that what is very badly wanted is a more sensitive controller. Liquid controllers meet the difficulty to a certain extent, but they are not altogether satisfactory; but I consider there is a lot of room for a really sensitive controller which would be more akin to the control of hydraulic cranes. Mr. Neele.

Mr. C. F. H. BAYLY: I have had to deal with several capstans on a certain railway, and it seems to me that they are in general of awkward design. So little room is usually left in the capstan pit that it is almost impossible to get into the pit to do repairs. Another point which Mr. Henderson mentioned was the heavy lids which create difficulties. The wires, switches, controllers, and other things that are put in are often exceedingly fragile, and with the continued damp the insulation breaks down and the wires rot away. A few more shillings spent in putting substantial materials into capstan pits, instead of cutting them down to the theoretical limit, would be amply repaid by immunity from breakdown. Another criticism I should like to make with regard to to these capstans is the difficulty of keeping one's foot on the pedal when there is a strong spring or counterweight acting against one and of having to handle the rope at the same time. It is necessary to get a certain weight on the rope to get the drum to bite, and it is very awkward to keep the weight on the pedal at the same time. The auxiliary switch shown by the authors, provided it does not open circuit until nearly at the top position, with a large foot-plate sinking flush in the ground, would be a great improvement on the usual pattern. Mr. Smith has referred to the question of speed in connection with cranes. I think it is a mistake to put too high a speed on capstans. One of our capstans had a speed of 270 ft. a minute, and we found it impossible for the man to draw the rope from the barrel at such a high speed. It was practically a waste, because it was found necessary to have one man to stand on the pedal while another man walked away with the end of the rope Mr. Bayly.

An objection to the use of series motors in capstans is the high speed with which they pick up the slack of the rope, causing a snatch as the load comes on which, owing to the inertia of the armature, etc., may severely test the rope.

Mr. R. H. WAITE (*communicated*): I note that Mr. Taylor makes reference to the arrangement adopted by Messrs. Stothert & Pitt, in connection with the crane barrel, and I think this is a decided advantage, especially for lowering purposes, but I do not quite agree with the author that any extra care need be exercised with a crane with the lifting barrel always in gear with a reversible motor; for if no protective is used to interrupt the current and so to apply the electromagnetic brake at a certain point (thus taking the matter out of the drivers hands), the inertia would be practically nil, if the electromagnetic brake, which it is assumed is included in every electric crane equipment, is properly adjusted. Mr. Waite.

DISCUSSION AT NEWCASTLE-UPON-TYNE, JANUARY 13, 1908.

Mr. Hunt.

Mr. F. O. HUNT: With reference to the control of jiggers by wire rope as described by Mr. Henderson, I think a better and more direct way would be a system of electrical multiple control similar to that used for push-button electrical lifts. As regards the electric capstans in outdoor situations, owing to temperature changes, moisture must condense inside of them. It is also very difficult to make contacts, etc., in an undergound chamber below capstans, and therefore the control gear ought to be above ground on a pole or pillar near at hand whenever possible.

Turning now to the block and fall system for raising wagons, the makers have not made use of the best point in this method, namely, that one cannot lift the cage above a certain point. The great drawback in this arrangement is the reverse bend in the steel ropes, which causes them to wear out very quickly.

Mr. Anderson.

Mr. J. A. ANDERSON: Can Mr. Henderson give any figures in regard to the units consumed and kilowatt demand for the whole warehouse? The figures would add greatly to the value of the paper. From some of his remarks I judge that some trouble has been experienced with the capstan's motors. Was the trouble confined to the starting-gear, or were the commutators affected by any improper use of the starter? As the load is not usually applied to the capstan before it is running full speed, I see no reason why the man operating on the rope has to keep his foot on the pedal. The starter can be made so that that pedal will stop in position when the resistance is all cut out. There is no reason why the operator should interfere with the starter while operating with the rope.

Are the circuit breakers in general use for all motors in the warehouse, or is their use only confined to capstans? In my experience with cranes, circuit breakers on each motor are a luxury, and are, as a rule, tied up by the craneman. With regard to the wagon hoist, I think a simpler arrangement could have been adopted if liquid resistance had been employed.

A direct-current supply is generally considered an ideal one for such a place, but a good deal can be said in favour of a 3-phase supply. It would be rather interesting to lay out a scheme for a 3-phase supply and compare the two. In regard to the overhead travellers, the wiring would be more complicated for 3-phase motors. It could, however, be simplified somewhat by using squirrel-cage motors for all motions, except hoisting, and starting them direct off the mains, by means of throw-over reversing switches. This method has been adopted successfully in some instances on Tyneside; the motors, however, may have to be slightly larger to get the necessary starting torque. In regard to the wagon hoist, I am not quite clear as to the arrangement, but I do not think there can be many difficulties in the way of adopting 3-phase motors. The control in this case might be operated by means of low-pressure current obtained from a small transformer.

In regard to the capstans they would undoubtedly be better in

every way if driven by 3-phase motors, and as far as I can see, squirrel-cage motors might be adopted, and they could be started up before the load was applied. In regard to the remaining plant, squirrel-cage motors could be adopted for all motions except hoisting. Mr. Anderson.

Taking all together, 3-phase installation would not cost any more than in the first instance, the extra cost for wiring would be more than covered by the saving in the cost of motors. The efficiency might be reduced a little, but this would be amply compensated by reduced maintainance and, what is just as important, fewer stoppages and less worry to the staff.

Mr. C. FARADAY PROCTOR: I should like to ask if any special precaution has been taken against damp in using fibre insulations. Mr. Proctor.

Mr. E. P. HOLLIS: I should like to know the speed of the capstans, also the speed of the motors driving them. Do the capstans rotate fast enough to permit of a direct drive? Mr. Hollis.

With reference to the motors. Why were they chosen compound-wound, and why was the series winding wound on separate poles, which, I suppose, are not commutating poles? Do these motors run sparklessly? I should like to know what kind of load factor is obtained in this class of work. The preference for direct-current over alternating-current working given here is indeed remarkable. In my experience, people who have had both direct-current and alternating-current cranes highly favour the latter, and when the former want replacing alternating-current cranes will be installed.

Mr. H. W. CLOTHIER: The paper points to the possibility of effecting remarkable economies by electric driving of cranes, etc., in railway warehouses. In the case quoted the cost of working was reduced from £600 to £150, and this is only, as it were, a patched-up job, in which the existing hydraulic cranes are retained, and driven by new electric motors. It is rather a pity that the very complete electric equipment at New Bridge Street has not been in use long enough for the publication of results, because, relatively, these should show very great saving in working costs. It would also be interesting to know how many thousands of pounds the North-Eastern Railway has saved in initial costs of building and plant by adopting electric driving. To judge from the paper and plans, this should amount to a very substantial sum. Mr. Clothier.

With regard to electric capstans, I confess to having made one once under circumstances which called for strict economy in the making. The motor was series wound, thus being simpler in connection than the author's compound motor. The deep tanks mentioned in the paper are costly and more cumbersome to handle, and I think that quite a good job, so far as inspection and repairs are concerned, can be obtained, as on my capstan, by providing four long set-screws through the flange of the top plate by which the whole can be raised two or three feet from the ground-level. The parts which require regular attention—that is, the brushes, the bearings, and the gear-box—were accessible by the removal of manhole covers. The idea of the starter was very simple. It consisted of an iron cylinder, fitted with a

Mr. Clothier. light piston floating in mercury and directly coupled with the treadle. When the latter was pressed down by the foot the motor circuit was closed through the starting resistance and the mercury was forced to the top of the float, from whence it passed through a hole and gradually filled another chamber in which the steps of the rheostat were placed, and inclined so that the mercury, in rising, gradually cut out the starting resistance. When the foot was released from the treadle the float would rise automatically and the motor circuit was opened. There was room for improvement, but it worked.

Mr. Cross. Mr. W. CROSS: I would point out the difficulty of getting at the electric capstans as compared with the arrangement of hydraulic capstans, where all the gear is fixed to the lid of the tank and can be slewed round for inspection. I think the switchgear seems rather complicated.

Mr. Longman. Mr. R. M. LONGMAN: I should like to ask if sparking occurs on the compound-wound capstan motors through having the shunt and series winding on separate poles? Can the author give us some information as to cost of upkeep of the special switch shown? I should like to know the reasons for adopting direct current instead of 3-phase.

Mr Pigg. Mr. J. PIGG (the Chairman): The design of the warehouse was settled some years ago and the contracts were placed, and in spite of the advance of 3-phase work the direct current has been adhered to.

DISCUSSION AT NEWCASTLE-UPON-TYNE, FEBRUARY 24, 1908.

Mr. Proctor. Mr. C. FARADAY PROCTOR: With reference to the cranes illustrated and described by Mr. Taylor, does not the free run-out with only the foot-brake control allow of too great speeds in the drop and heavy strains on the crane when the brake is applied? It used to be considered dangerous to attach a rope direct to the capstan head, as the accidental starting might cause serious results. It is now the practice to take two turns of rope round the bollard and start the movement by pulling the loose end.

Mr. Clatworthy. Mr. W. A. CLATWORTHY: I should like to ask whether the fact that practically the same horse-power is absorbed by the conveyors at any inclination does not show that the bulk of the power is used in overcoming mechanical friction.

Mr. Sleigh. Mr. J. P. SLEIGH: The height through which the coal was lifted was not recorded in the test, and therefore one could not determine the efficiency of the gear. I should like to know if the figure of 0·017 units per ton was high or low.

Mr. Law. Mr. A. H. LAW: The installation is driven by 3-phase motors, but I think continuous-current motors would be much better. I should like to know how the motors were controlled.

Mr. Brooking. Mr. J. H. C. BROOKING: With reference to the plug boxes, if they are level with the quay they get full of dirt as the cover is not always replaced after use, and this is apt to lead to short circuits. I think a better way would be to have a feeder pillar. A few years ago more

cranes were stopped through the plug boxes than by breakdowns in motors. Mr. Brooking.

Mr. J. A. ANDERSON: I should like to know if any trouble has been experienced with the friction clutches in capstans, and if the auxiliary motor of the hydraulic plant automatic starter is of the same voltage as the main motor. I think a standard controller operated hydraulically would be better. It is possible that in winter trouble may occur through the water freezing, but in plant of this type which I have seen no trouble from this cause had been experienced. Mr. Anderson.

Mr. F. O. HUNT: With reference to the test upon an inclined conveyor on which the power absorption was found to be constant, it would be interesting to know to what limit the constancy extended, and what happened at the horizontal position and below it. Mr. Hunt.

Mr. H. HENDERSON (*in reply*): I quite agree with all the speakers who have made remarks about the speeds of the machinery described. These are undoubtedly high, and when a complete set of operations is considered, the time occupied in lifting, even at a slow speed, is a small proportion of the total time occupied. Thus a high lifting speed is not such a gain as would appear. The cranes are provided with an overrunning switch, operated by a screw on the end of one of the shafts. The arrangement works correctly, except at light loads, as the momentum of the gearing, etc., is sufficient to cause a certain amount of running after the switch is opened. The most reliable plan is to employ a good driver, and he will soon learn to handle the crane in such a manner that the overrunning switches will never come into operation. In the capstans the speed is again high. The power required as per rating, allowing 85 per cent. efficiency, is certainly 20, but this efficiency seems to be high, and also a considerable allowance must be made for the slip of the head inside the rope. Electric capstans are notorious for wearing out ropes, a fact entirely due to the high speed. It is certainly preferable to mount all the electric switchgear in a separate box, outside the capstan. If the capstan is in the open, a pillar box could be fixed in the vicinity. This would cost very little extra money and would soon pay for itself. Condensation of moisture is the cause of the trouble with capstans. We have tried heaters, and found them expensive. We also tried keeping the shunts alive on the motors. This was found to cause trouble when the circuit breaker at the power station opened. The only remedy is to put in a totally enclosed motor and keep all switchgear, with the exception of the treadle switch, outside the capstan tank. I quite agree with Mr. Bayly in respect to the heavy lids on some capstans. They take two men to lift them, and this is sometimes a serious item. In some designs, after having managed to raise the lid, a man cannot get at any apparatus beyond the commutator of the motor. I have seen men have to lie on their backs to connect up a resistance. Such things add so greatly to the cost of maintenance that any saving in power is soon taken up in waste of time in maintenance. Careful thought Mr. Henderson.

Mr Henderson.

on the part of those who design and manufacture capstans would make things so easy that an electrical capstan could run for long intervals with little attention. I prefer compound-wound motors, as they will give an even turning effort and also no special machinery is required for light running. The friction brake mentioned by Mr. Smith is similar to those on the wagon hoists described. These contain water, and if the capstan was outside, trouble would arise from freezing in winter.

The material to be dealt with by the wagon hoists will be chiefly potatoes and provisions in bulk. These could not be unloaded on to a travelling belt or conveyor. It is thus necessary to lower the wagon with its load into the cellar.

Mr. Smith has misunderstood the arrangement of the travelling cranes used at the Forth warehouse. The lattice work is not alive, but the rails upon which the travellers run are. The rails are well insulated, and have proved so satisfactory that we have had no breakdown of the insulation for over five years. The arrangement gives less trouble than a pair of trolleys and wires would have done, owing to the peculiar shape of the track.

In reply to the discussion at Newcastle.—Owing to the amount of work involved, the mechanical control for jiggers has been found to be best. Moisture is the chief trouble in capstans, and where electrical gear is difficult to get at the cost of maintenance is very much increased. We do not yet know the load factor, as the place is not yet in full use. Automatic circuit breakers are fitted to each capstan, and there are breakers on main power circuits which are also protected by fuses.

With regard to the traverser at Forth Goods Station, the design is unusual, but by bushing the wheels with dished mica bushes and using insulated bolts, no trouble has been experienced in four or five years' working. The reason for having shunt and series windings on separate poles of the 4-pole motor is that the depth of the poles is limited owing to lack of space.

There has been no trouble with flashing between brushes. I think the idea of mounting the capstan electrical gear on the tank lid is very good if there is grease lubrication.

Mr. Taylor.

Mr. C. E. TAYLOR (*in reply*): With regard to Mr. Smith's question, the belt of the coal conveyor illustrated in the paper is composed of plates 10 in. broad, and can be used as an ordinary gravitation spout if required without the use of the motor; in some other conveyors which have been fixed the belt is composed of a mixture of canvas and rubber. I do not know of any trouble having been experienced with the centrifugal governor on the anti-coal-breaker; the brake is very satisfactory and adjusts the speed very well. With regard to liquid controllers, I do not think these are very suitable for continuous working.

In reply to the discussion at Newcastle.—When lowering loads with the cranes the foot brake is always on to a certain extent, so as not to allow of too great speeds being attained, and with cranes of this type a good factor of safety is allowed.

Mr. Taylor.

The horse-power required for the conveyors running light is 6·5, and therefore Mr. Clatworthy's contention that the bulk of the power is required to overcome friction is not quite correct.

The installation is driven by 3-phase motors because the supply is 3-phase, and would have necessitated transformation if direct current motors had been used, and I see no reason why 3-phase is not as good as direct current for this work. The arrangement of controllers is shown in the paper.

With reference to friction clutches in capstans no difficulty has been experienced with these after they have been properly adjusted. The voltage of the auxiliary motor on the automatic starting switch is not the same as the pump motor, but is 220 volts. The operation of controllers is largely a matter of experience, and we have not hitherto had any controllers operated by hydraulic power.

With reference to Mr. Sleigh's remarks, I may point out that the length of conveyor and its elevation from the horizontal were given in the paper, and from that the total height through which the coal was raised is 11 ft.

With reference to Mr. Brooking's remark, no trouble has been found to arise with the arrangements shown in the paper.

When the conveyor is used on a downward incline, it is used as an ordinary chute, provided the gradient is sufficient.

On the motion of the President a hearty vote of thanks was accorded to Mr. Henderson and Mr. Taylor for their papers.

Proceedings of the Four Hundred and Seventy-First Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 5th, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on February 20, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Ashton Bremner.	Arthur P. Patey.
James F. Heath.	Frank Powell.

From the class of Associates to that of Members :—

James W. Woods.

From the class of Associates to that of Associate Members :—

William B. Pye.	L. U. Vignoles.
Professor David Dobertson.	Thos. C. Woolams.

From the class of Students to that of Associate Members :—

James Auckland.	J. W. Maitland.
Alfred S. Cross.	Ernest R. Myers.
E. L. Gosset.	R. M. Sethma.
Donald Maclean.	Norman Thirlby.

C. T. Wilkinson.

Dr. D. K. Morris and Mr. A. D. Stevenson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Harold Edmund Ironside Bax.
Carl Bollam.
Herbert Mackenzie Cuff.
Frederick John Gerrard.
William James Gray.
Thomas Hall.
Thomas Henry Hurst.
Harold Lees.
Arthur Newcombe Rye.
Donald Sinclair.
Edward James Stevens, Lieut., R.A.
Herbert Ellery Turner.
Christopher Wade.
John Maurice Walshe.
Arthur Ernest Wilkins.
John William Finch Wyatt.

As Students.

William Herbert Apthorpe.
Joseph William Arnott.
Ralph Henry Barbour.
William Richard Brown.
H. C. Chindian.
Nathaniel John Cook.
Harold Chappell Ellis.
Sayed Fahmy.
Albert Chitty Fendick.
John Fleming.
William Stanley Gould.
Roger Ernest Grime.
Harry Holman Hayhurst.
George Stanley Helme.
Joseph Augustine Hogan.
William Holt.
Reginald George Isaacs.
Hugh Jack, B.Sc.
Herbert Ferrier Jefferson.
Frederick Henry R. Lavender.
Sydney William Ledbrook.
Dougal Campbell McPherson.
Henry James Magrath.
George Victor Massey.
George Taylor Medforth.
William Arnold Olds.
Cleovule Papageorge.
Warner Hutchins Peberdy.
William Pitt.
Harry William F. Pouter.
J. L. Ridsdale.
Alex. Thornton Robertson.
Charles Irving Roddick.
Charles Geoffrey Saltren-Willett.
Albert George Savill.
John Franklin Shipley.
Gerald McKenzie S. Sichel.
Percy Smith.
Sydney Thompson.
Arnold Dumont Villares.
John Douglas A. Vincent.
Arthur Wadsworth.

Donations to the *Building Fund* were announced as having been received since the last meeting from Mr. F. H. Nicholson ; and to the *Benevolent Fund* from Mr. W. C. P. Tapper and Mr. F. H. Nicholson, to whom the thanks of the meeting were duly accorded.

The following paper was then read and discussed :—

FUSE PHENOMENA.

By Professor ALFRED SCHWARTZ, Member, and W. H. N. JAMES, Associate Member.

(*Received from the* MANCHESTER LOCAL SECTION, *January* 16, *read at Manchester on March* 3, *and at London on March* 5, 1908.)

The selection of a metal for a fuse is a matter which requires some discrimination, and no hard-and-fast rules can be laid down to suit all cases.

The following factors have to be considered:—

I. The degree of purity of the metal, or the constancy of composition of the alloy, obtainable commercially and its cost.
II. The melting-point of the fuse.
III. The specific resistance of the metal and the coefficient of increase of resistance with temperature.
IV. The liability to oxidation and the condition of the oxide sheath, whether solid or fluid at the temperature of fusion of the wire.
V. The mass of metal required for a given service.
VI. The properties of the metal vapour for sustaining an arc.
VII. The time element of the fuse.

I. THE PURITY OF THE METAL.

With regard to this factor, the importance of employing a material which can easily be obtained of standard composition is generally understood; but, notwithstanding this, a very large amount of alloy wire and strip is still used, the composition of which is a very uncertain quantity. It is true that many of these metals have lower melting-points than those of the pure metals in use as fuses, but this does not outweigh the advantage of constancy of composition which a pure metal such as copper possesses.

II. THE MELTING-POINT.

This is concerned with—

(*a*) The fire risk.
(*b*) The method of connecting the fuse to the fuse contacts on the carrier.
(*c*) The character of the "jacket" material for enclosed fuses.

Fire Risk.—The fire risk with metals of low melting-point is due to the scattering of molten particles when the fuse blows, or to the persistence of the arc across the terminals. With metals of high melting-

point there is an additional risk due to the fuse becoming red hot before fusion.

As special points in connection with the fire risk, the liability of some metals, such as zinc, to burn in air at the temperature of disruption must be considered; and with enclosed fuses fitted with indicator wires, it must be borne in mind that this wire practically forms an open fuse of small capacity. Experience has shown that the flash from such an indicator is sufficient to ignite combustible material in the vicinity.

Further, in the case of enclosed fuses, unless hermetically sealed or provided with special arrangements referred to hereafter for preventing the ejection of molten metal, both flame and molten metal may issue from the ends.

Method of Connecting the Fuse to the Fuse Contacts on the Carrier.—In enclosed cut-outs the fuse is usually soldered to stout copper wires or lugs, which are in turn soldered to the metal end caps of the cartridge, and extend inwards inside the cartridge for a considerable distance.

In the first place, it is to be noted that with an enclosed cut-out of this character it is impossible to judge of the actual length of break employed from a consideration of the outside overall length between the end caps or fuse contacts.

Secondly, there are in such fuses four soldered joints, and if these are not carefully made, sufficient local heating may be set up to blow the fuse prematurely or to char the jacket if a combustible material, such as red fibre, is employed.

With metals of low melting-point this arrangement seems to be adopted to avoid damage to the end caps from the arc, and also to allow the soldering of the fuse to the lugs before placing it in the cartridge, thus enabling this joint, which is between copper and a metal with low fusing-point, to be made under favourable conditions. The final soldering of the lugs to the end caps being between metals of high melting-point presents no difficulty.

Jacket Material for Enclosed Fuses.—The character of the jacket material for enclosed fuses is largely determined by the metal employed for the fuse.

The jacket materials employed commercially at the present time are as follows:—

Red or black fibre.
Glass.
Porcelain.
Metal tube with an insulated liner usually of mica or asbestos.

The fibre material is easily worked, but is combustible, absorbs moisture, and deteriorates on heating. It can only be employed with fuse metals of low melting-points; the low melting-point of the metal does not prevent a high temperature being developed by the arc if this holds for any length of time.

Fibre is used very largely in the United States, and possesses the advantage of being tough and not easily broken by ill-usage or on the blowing of the fuse.

Frequently the fixing of the end caps to the fibre tube is not substantial enough; where rivets are employed, they are commonly placed too near to the end of the tube, and the end caps are in consequence easily blown off.

Glass is not much used for enclosed fuses, as it is not so strong as porcelain.

Porcelain would seem to be the most suitable material for jackets; it, however, does not lend itself so easily to connection with the fuse contacts, and is also more expensive than fibre.

At first sight the metal tube would appear to offer advantages from the point of view of incombustibility, strength, and cooling; its use, however, is complicated by the necessity of using an internal liner of insulating material to protect the tube from the arc and of insulating bushes to separate it from the fuse contacts.

As regards strength, if the cut-out is properly designed and constructed, the pressure developed on blowing should not be great.

With regard to cooling, the jacket material does not usually play an important part, as this is largely determined by the character and disposition of the filling.

III. The Specific Resistance and Coefficient of Increase of Resistance with Temperature.

On low-voltage circuits the resistance of the fuse itself forms a considerable portion of the total resistance of the circuit, and therefore plays a not inconsiderable part in limiting the current rush on short circuit. With higher voltages this effect is of less importance.

Table I.

Physical Constants for Metals employed as Fuses.

	Lead.	Copper.	Silver.	Tin.	Zinc.	Cadmium.	Aluminium.
Density	11·3	8·95	10·5	7·4	7·15	8·64	2·60
Melting-point °C.	327	1,054	954	230	412	321	657
Boiling-point °C.	1,173	2,100	—	1,450–1,600	930	782	—
Specific resistance in legal microhms at 0° C. centimetre measure	19·4700	1·6200	1·4680	13·1000	5·8000	10·0200	2·6600
Temperature coefficient for resistance 0°–100° C. ...	0·0041	0·0043	0·0040	0·0044	0·0038	0·0042	0·0043
Specific heat in neighbourhood of melting-point in gramme calories ...	0·0360	0·1180	0·0748	0·0637	0·1040	0·0617	0·3077
Relative mass of metal required for a fuse of normal fusing current = 20 amperes, copper = 1	—	1·0000	1·6600	9·9000	4·1000	—	*0·8200

* In the case of aluminium a light spring attachment was used to break the circuit as soon as the wire melted.

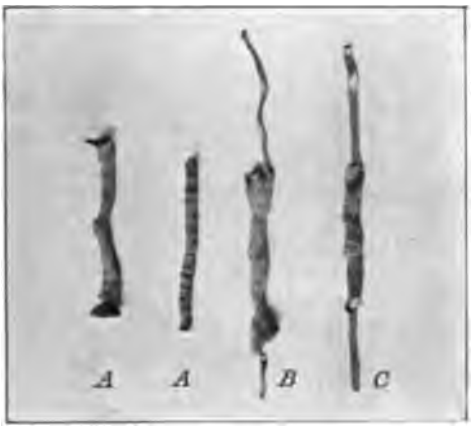


Fig. 1.—Photograph of Tubes formed in Enclosed Fuses with Calais Sand Filling with Fuses of different Metals.

N.F.C. in air, 20 amperes approximately.

A. Copper. B. Tin. C. Zinc.

TABLE II.

Relative Quantities of Heat at the Moment of Melting in Fuses of various Metals, but of the same Normal Fusing Current.

Metal.	Approximate Relative Quantity of Heat in Fuse of 20-ampere Capacity at Moment of Fusion.
Copper	1·00
Aluminium (with spring attachment) ...	1·20
Silver	0·90
Tin	1·26
Zinc	1·53

Although the quantity of heat in the fuse at disruption may be considered as some criterion for selecting a metal from the fire-risk point of view, yet in our view this consideration is outweighed by others, such as the capacity of the metal for maintaining an arc, the surface tension of the molten metal as influencing the way in which it segregates into globules, the behaviour of the globules of metal after disruption as to whether they burn in air or not.

Further, a reference to Table I. shows that the boiling-points of metals with low melting-points, such as lead, tin, and zinc, are in the neighbourhood of 1,000° C., and it is certain that many of the globules of these metals, which are scattered on disruption, approximate to this temperature.

Tin, for instance, melts at 230° C., and Fig. 6B shows an actual photograph of a tin fuse on a limited short circuit. The numerous white streaks radiating from the fuse mark the paths of globules of molten metal, and it is evident that these globules must have attained a sufficiently high temperature to have become luminous.

In general, it may be taken that the mass of metal in the fuse should be kept as small as possible for open-type fuses; for enclosed fuses this point has to be considered in connection with the temperature which the jacket material will stand, as the metals with small mass necessarily have a high melting-point and will attain red heat before fusion. In the screened shunted type of fuse it would seem possible to employ a metal with large mass and low melting-point for the main fuse, as this will melt quite quietly, the break being made on the shunt, which is of high resistance, and is enclosed or protected.

For fuses of large capacity this type is worthy of more attention than has hitherto been paid to it.

VI. THE CAPACITY OF THE METAL FOR MAINTAINING AN ARC.

We have studied this condition in three ways—

1. By photographing the fuse itself where blowing.
2. By observing the minimum length of break at which on short circuit the character and duration of the arc are such that little or no damage is done to the terminals.
3. By oscillograms of the current rush and inductive pressure-rise on short-circuiting the fuse.

The factors which have to be considered are given below, and will be discussed seriatim :—

(*a*) The intensity of the short-circuit current.
(*b*) The capacity of the fuse.
(*c*) The pressure of the circuit.
(*d*) The character of the fuse metal.
(*e*) The inductance of the circuit.
(*f*) The disposition of the cables or conductors to the fuse terminals.
(*g*) The mass of the fuse terminals.
(*h*) The character and disposition of the filling for enclosed fuses.

The Intensity of the Short-circuit Current.—The terms "short circuit" and "dead short circuit" are used very loosely, and as the amount of current flowing on short circuit largely affects the behaviour of the

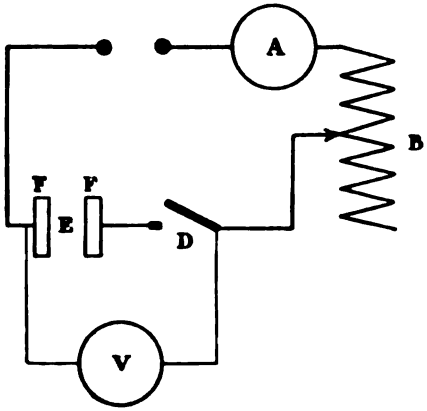


FIG. 2.—Diagram of Arrangements for Short-circuit Tests.

A. Ammeter to read Normal Fusing Current.
B. Adjustable low resistance
D. Main switch.
F. Fuse terminals.
V. Voltmeter for circuit voltage.

fuse on disruption it becomes necessary to define it more strictly. This can be done by specifying the drop in volts in the leads with the normal fusing current of the fuse under test flowing; thus a 3 per cent. drop in volts would allow of a short-circuit current equal to thirty-three times the normal fusing current of the fuse under test, a 10 per cent. drop of ten times the normal fusing current, and so on.

A diagram of the testing arrangements employed by us is given in Fig. 2. The method of working was as follows: Across the terminals F in lieu of the fuse was placed an adjustable resistance E sufficient to carry the normal fusing current of the fuse under test.

For large currents this resistance may be of such size as to carry one-half or one-third of the normal fusing current, the drop in this case being adjusted to one-half or one-third of the drop that would be obtained with the full normal fusing current.

The switch D was then closed and the resistance E adjusted, so that the ammeter A read the normal fusing current of the fuse under test.

The resistance B was adjusted so that the difference in readings on the voltmeter V with the switch D open and closed was the required drop. It is necessary that the resistance B should be small compared to the resistance E; an alteration in the value of B will alter the current read at A, and will necessitate a slight readjustment of E.

The resistance E was now removed and replaced by the fuse.

The 3 per cent. drop in pressure referred to has been found to be representative of the conditions likely to be met with in house services for main and distribution board fuses.

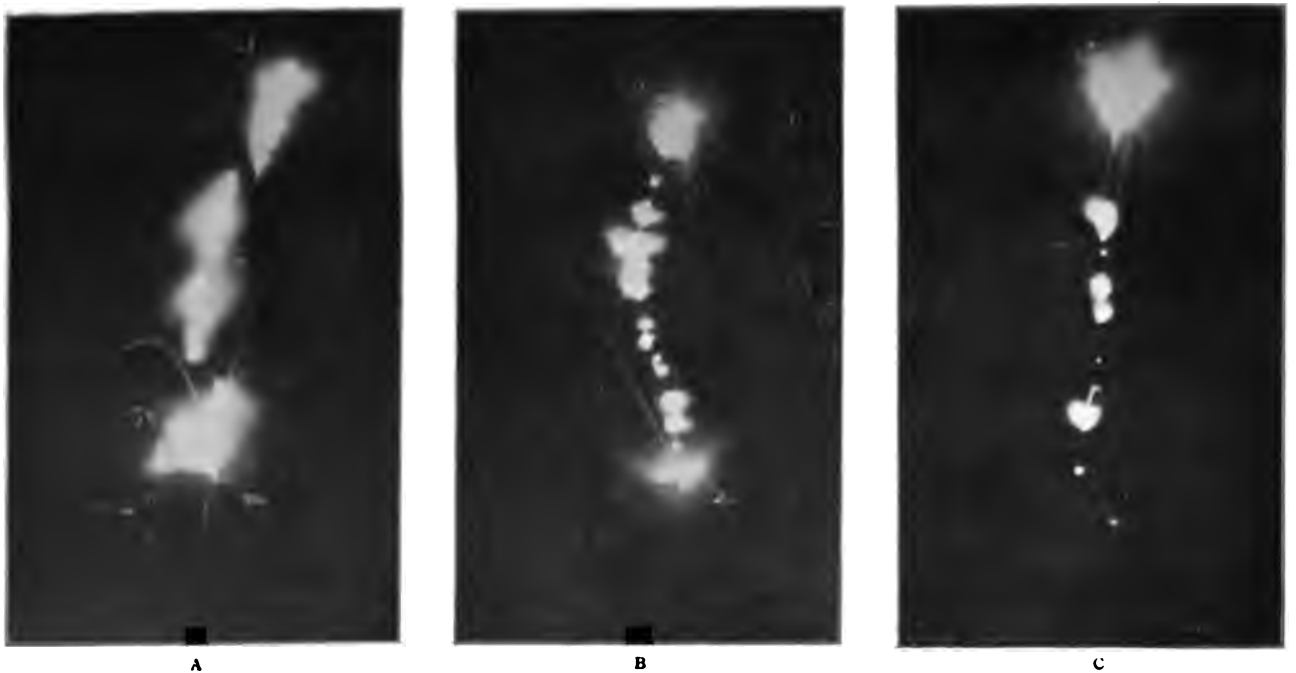
As already stated, the minimum length of break was taken as the least length at which no damage was done to the terminals on short circuit, the resistance of the circuit being such as to give a 3 per cent. drop with the normal fusing current flowing.

Under these conditions a length is obtained at which there may be said to be "no arc," although, strictly speaking, an arc results every time a fuse blows, but in the above-mentioned case its duration is so short that no damage is done to the terminals. This length will be referred to hereafter as the "minimum no-arc length."

In carrying out experiments on the minimum no-arc length it was found that there was a greater tendency for an arc to form across clean, freshly fused surfaces than across dirty surfaces, and since in these experiments the object was to get an arc if possible, short lengths were first taken with which an arc was formed. The length of fuse was then gradually increased until a point was reached at which at least three successive fuses of the same length were blown without an arc resulting. Under these circumstances the surface of the terminals for each new length of fuse experimented with was a clean one across which an arc had recently taken place.

If, instead of proceeding as above, a long length is taken such that on blowing no arc to the terminals takes place, and this length is gradually reduced until an arc is formed, a much shorter minimum no-arc length will be obtained, since in this case each fresh length is tried with a dirty terminal surface.

We find that for copper wires of 20 amperes N.F.C. and upwards on a 220-volt circuit the minimum no-arc length increases slightly as the drop in pressure in the circuit is reduced. The following values are each the result of about twenty experiments with a 27-ampere (No. 25 S.W.G.) open-type copper fuse with large terminals (350 gm.) on a 220-volt circuit:—



A B C

FIG. 3.—Photographs of an Open-type Copper Fuse, blowing on a 220-volt Inductive Circuit with various Short-circuit Currents,

A. Short-circuit current = 33 × N.F.C.
B. " " = 10 × N.F.C.
C. " " = 5 × N.F.C.

N.F.C. in air, 20 amperes. Length of fuse, 3 in

usual way, the room is darkened and the plate exposed; the fuse is then blown and emits sufficient light to produce the photograph. These photographs, of course, give an integration of the whole phenomenon, and it is not possible to state from a consideration of them the time sequence in which the arcs are produced, but as the whole process only occupies a few hundredths of a second there are certain deductions which we may be warranted in making.

It is well known from visual observations that a fuse blowing with a small overload melts first at the centre, where an arc is established which burns back towards the fuse terminals, whereas on short circuit the whole length of wire is disrupted practically simultaneously.

The striking point in the photographs under consideration is the large number of arcs that are developed. It would seem that the wire becomes molten along its whole length, and that under the influence of surface tension it segregates into a number of beads or globules the arcs forming between the beads where the cross-sectional area is reduced, the heat developed at these points being sufficient to vaporise the metal. The straight and curved white lines appearing in the photographs mark the paths of glowing globules of metal which have been ejected. The outline of the clamp terminals may be discerned, and in each case it will be seen that an arc has been formed to one or both of them. It will be noticed that with a short-circuit current $= 33 \times$ N.F.C. (Fig. 3 A) the wire seems to be broken up into several portions, whereas in Fig. 3 B, with a short-circuit current $= 10 \times$ N.F.C., less explosive violence has been developed, and in consequence a chain of small arcs has been formed between the terminals. It may well be, therefore, that under these latter conditions the arc may hold over a greater length of break, as is shown to be the case in the experiments given in Table III.

The magnetic blow-out effect due to the leads may also assist. The fuse in the photographs given was vertical in each case, but the arcs seems to have been deflected; this effect will be referred to in detail later. With enclosed fuses it was found that the results of short circuits were much more severe with $33 \times$ N.F.C. than with $10 \times$ N.F.C.

This conclusion is based on a large number of visual observations; only a small number of actual determinations of minimum no-arc lengths were made, but these support the above conclusion, as the following example shows:—

Copper fuse N.F.C. = 10·6 on 220-volt inductive circuit no-arc length with $33 \times$ N.F.C. = 1·7 in.
" " " " $10 \times$ N.F.C. = 1·3 in.

In all subsequent experiments, unless otherwise stated, $33 \times$ N.F.C. has been taken as the standard short-circuit current.

Variation of Minimum No-arc Length with the Capacity of the Fuse for a given Metal.—The minimum no-arc length for open-type fuses of a given metal increases with the capacity of the fuse, but not proportionally. The curve connecting the minimum no-arc length and the

normal fusing current for open-type copper fuses on 220-volt non-inductive circuit (that is, with the inductance due to the generator and cables only) with short-circuit currents $= 33 \times$ N.F.C. is given in Fig. 4, curve A.

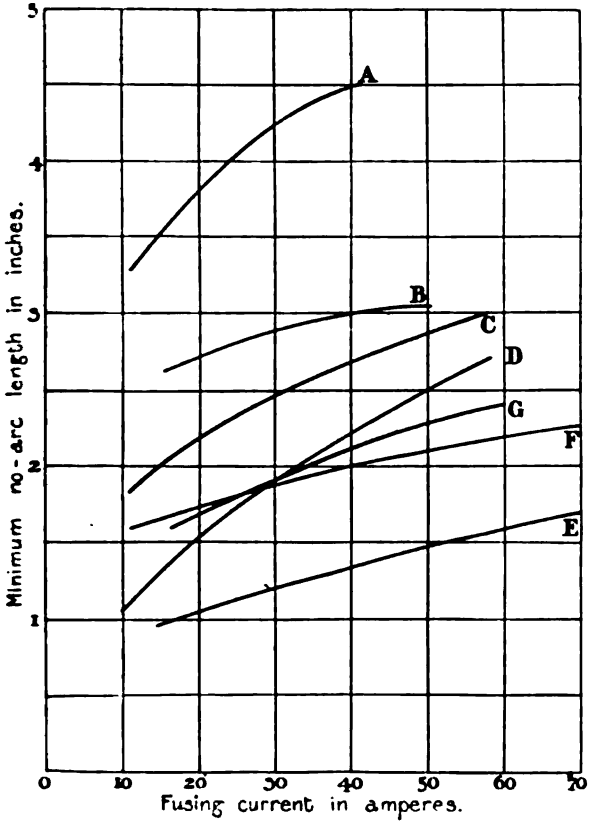


FIG. 4.

A. Copper wire free in air.
B. Zinc strip free in air.
C. Copper wire in tubular holder.
D Copper wire passing through asbestos partition at centre.
E. Copper wire enclosed with Calais sand filling.
F. Copper wire enclosed on inductive circuit.
G Zinc strip enclosed on non-inductive circuit.

All the above on 220-volt circuit A to E, non-inductive; F, inductive (0·023 henry).

These curves follow a law of the character of $D = A + B(N.F.C.)^n$, where—

D = minimum no-arc length;
N.F.C. = normal fusing current;
A, B, and n = constants depending on the metal employed and on other factors (n being less than 1).

With enclosed fuses the minimum no-arc length increases with the capacity of the fuse much in the same way as in the open type. The results for copper fuses up to 50 amperes on a 220-volt non-inductive circuit are shown graphically in Fig. 4, curve E.

Variation of Minimum No-arc Length with the Pressure of the Circuit.—Experiments were carried out at pressures of 110 and 220 volts on open- and enclosed-type fuses, the results of which are embodied in Table IV.

TABLE IV.

Variation of Minimum No-arc Length with Circuit Voltage for Copper Wires on a Non-inductive Circuit.

Description of Fuse.			Minimum No-arc Length in Inches.		Ratio. $\frac{A}{B}$
N.F.C. in Amperes.	Terminals.	Short-circuit Current.	A 220 Volts.	B 110 Volts.	
			Inches.	Inches.	
10·6	Small	33 × N.F.C.	2·70	1·25	2·16
10·6	Large	33 × N.F.C.	1·70	0·80	2·12
10·6	Small	10 × N.F.C.	3·20	1·50	2·13
27·0	Large	33 × N.F.C.	3·60	1·10	3·27
27·0	Large	10 × N.F.C.	2·90	1·45	2·00
27·0	Small	10 × N.F.C.	3·05	1·10	2·76
10·6	Small	5 × N.F.C.	2·50	1·30	1·92
10·6	Large	5 × N.F.C.	3·00	1·10	2·73
27·0	Large	5 × N.F.C.	3·25	1·50	2·13

A consideration of this table shows that for open-type fuses the increase in length of the minimum no-arc length is at least in proportion to the increase in the circuit pressure for the ranges given.

G. Meyer, in a recent paper,* gives curves connecting the normal fusing current, and the length of wire melted with the normal fusing current flowing at a given voltage, for copper fuses in a tubular porcelain holder. The effect of increase in circuit voltage in increasing the length of wire melted is very clearly seen in Fig. 5, by contrasting curve B, for copper at 2 volts, with curve C, which is for copper at 102 volts.

These curves are, however, of no service in determining the minimum no-arc length, as they only give the length of wire melted with the normal fusing current flowing at various pressures. A consideration of Meyer's curves shows that the length of wire melted tends to become constant for currents above 150 amperes with a given circuit pressure; it is evident, therefore, that quite a different set of phenomena is introduced on short circuit when the wire is disrupted from terminal to terminal.

* Theoretisches und Praktisches über Abschmelzsicherungen, *Elektrotechnische Zeitschrift*, vol. 28, pp. 430, 460, 1136, 1158.

Variation of the Minimum No-arc Length with the Character of the Fuse Metal.—The curve connecting the minimum no-arc length with the normal fusing current for copper wires in open-type cut-outs

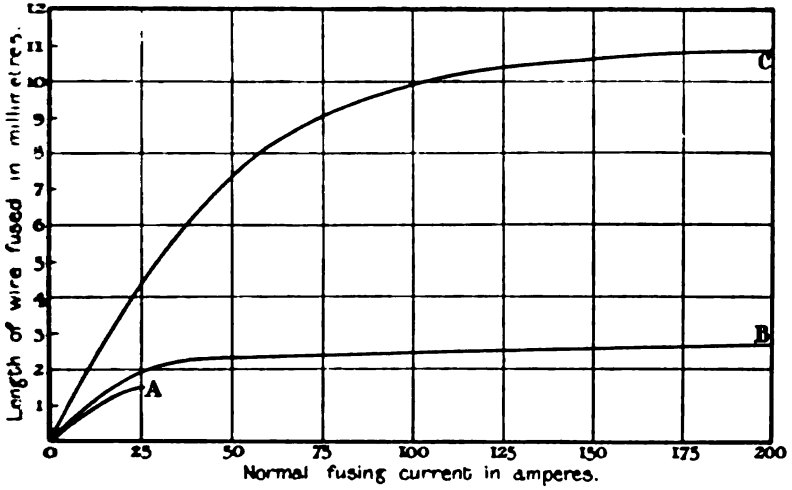


FIG. 5 (Meyer).—Curves connecting Normal Fusing Current and Length of Wire fused for various Circuit Pressures.

A. Zinc at 2 volts.
B. Copper at 2 volts.
C. Copper at 102 volts.

has already been given in Fig. 4 (curve A) for short-circuit currents = 33 × N.F.C. and 10 × N.F.C., whichever gave the greater length.

TABLE V.

Minimum No-arc Length for Open-type Fuses of Copper and Zinc on 220-volt Non-inductive Circuit. Short-circuit Current = 33 × N.F.C.

Fuse Metal.	Normal Fusing Current in Amperes in Air.	Minimum No-arc Length in Inches.	
		Zinc.	Copper.
Zinc	26·0	2·85	4·2
Copper	27·0		
Zinc	45·0	3·05	4·5
Copper	41·5		

Under the same conditions in open-type fuses the minimum no-arc length for zinc is decidedly less than that for copper. The results of about twenty experiments in each case are given for the two metals in question in Table V.

Zinc blows fairly cleanly; the molten metal is not scattered far, but occasionally some globules show a tendency to continue to burn in air where they fall. On the whole it is a good material from a short-circuit point of view. A photograph of an open-type zinc fuse for 20 amperes blowing with a short-circuit current of 200 amperes is given at A, Fig. 6.

Tin in open-type cut-outs with short-circuit currents of ten times the normal fusing current behaves very much like copper with short-circuit currents limited to two or three times the normal fusing current; that is to say, it blows softly and quietly, and it is difficult to state from visual observation when arcing takes place.

It may be taken that the damage to terminals with tin in lengths commonly employed is slight with short-circuit currents of ten times the normal fusing current.

With 20- or 30-ampere fuses and short-circuit currents of 33 × N.F.C. there is, however, a great display of fireworks, accompanied by copious fumes, and with the lengths commonly used severe damage to terminals is likely to ensue. A photograph of a 20-ampere tin fuse blowing with a short-circuit current of 200 amperes is shown at B, Fig. 6.

With enclosed fuses the minimum no-arc length was found to be somewhat greater for zinc than for copper; this is due to the greater mass of metal involved for a fuse of a given capacity and to the molten metal being confined by the filling, and possibly also to the metal vapour not being so quickly oxidised as when the fuse is in air. As already stated, in open-type cut-outs this effect is reversed, the zinc giving the shorter minimum no-arc length. The following examples given in Table VI. for copper and zinc in enclosed fuses are typical :—

TABLE VI.

Minimum No-arc Length for Copper and Zinc in Enclosed Fuses with Calais Sand Filling 220-volt Non-inductive Circuit. Short-circuit Current = 33 × N.F.C.

Fuse Metal.	Normal Fusing Current in Amperes in Air.	Minimum No-arc Length in Inches.
Zinc	25	1·8
Copper	27	1·3
Zinc	45	2·2
Copper	43	1·6



A B

FIG. 6.—Photographs of Open-type Zinc and Tin Fuses, blowing on 220-volt Circuit.

A. Zinc short-circuit current = 10 × N.F.C.
B. Tin " " = 10 × N.F.C.
N.F.C. in air, 20 amperes. Length, 3 in.



The minimum no-arc lengths for enclosed fuses of copper and zinc under various conditions and for fuses up to 50 amperes are given in Fig. 4. In inductive circuits zinc gives lengths about 20 per cent. greater than those given in Fig. 4, which are for non-inductive circuits. Tin gives a length rather greater than zinc in each case.

That the different metals behave in a characteristic manner on fusion with regard to the duration of the current rush on short circuit, the tendency of the arc to persist, and the inductive pressure rise on breaking the circuit, may be seen from the oscillograms given in Fig. 8.

These oscillograms have been selected from a large number obtained for various metals, and are typical of the metals named. The

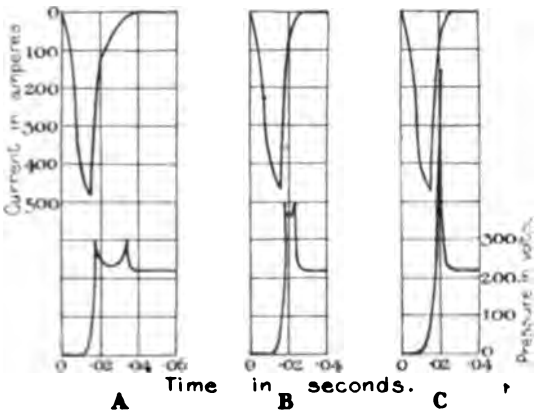


FIG. 7.—Oscillograms showing the Influence of Tightness of Packing in the Fillings for Enclosed Fuses.

A Copper wire in bone ash loosely packed.
B Copper wire in bone ash tightly packed.
C. Copper wire in plaster of Paris (equivalent to a very tight packing).
N.F.C for copper wire in air = 20 amperes. 220-volt inductive circuit (0·023 henry).

following is a brief *résumé* of the points observable from the oscillograms :—

Copper, Fig. 8 A, open-type 110-volt inductive circuit.—The inductive pressure rise is usually only moderate, as the arc persists for a definite but short time.

Fig. 8 B, open-type 220-volt inductive circuit.—The arc persists for a considerably longer period ; the voltage rise is fairly small and irregular. The current rush does not rise to the value determined by the resistance of the circuit owing to the quick action of the fuse.

Fig. 8 C, enclosed-type 220-volt inductive circuit.—The double rise shown here is very characteristic of copper.

Tin, Fig. 8 D, open-type 110-volt inductive circuit.—The inductive pressure rise is usually higher than that of copper, and the duration of the arc is less. Occasionally a considerable voltage rise is obtained (Fig. 8 E).

Silver, Fig. 8 H.—Behaves very similarly to copper, the duration of the arc being slightly longer and the inductive pressure rise about the same.

Aluminium, Fig. 8 I, 110-volt inductive circuit.—The inductive voltage curve is usually very peaked in shape, its maximum being higher than that of tin. Sometimes a double peak is obtained, and in these cases the voltage rise is about the same as for tin.

Fig. 8 J, 220-volt inductive circuit.—The voltage rise is small, being less than in the 110-volt case, as the arc persists for a considerably longer period.

Cadmium, Fig. 8 K, 110-volt inductive circuit.—The inductive voltage curve is usually very irregular, probably owing to the instability of the arc; its maximum is rather greater than that for zinc, and it takes a considerable time to die away.

Fig. 8 L, 220-volt inductive circuit.—Resembles aluminium, and although the inductive pressure rise is rather greater than with copper, it is better than copper from the point of view of the duration of the arc.

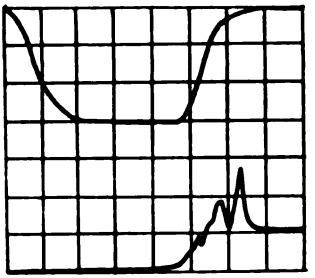
Fig. 8 M.—The gradual fall in the current after fusion and the gradual rise in pressure to the normal circuit voltage with the small final inductive rise seems to indicate that the tube formed in the Calais sand filling while hot was acting as a conductor as already referred to.

Zinc, Fig. 8 N, open-type 110-volt inductive circuit.—Like aluminium, gives rise to a high inductive voltage rise; the form of the curve suggests instability of the arc.

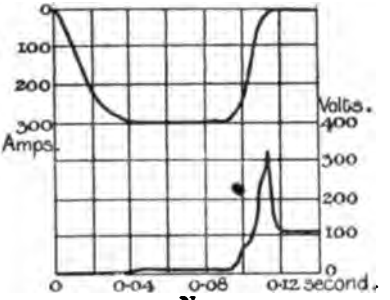
Fig. 8 O, open-type 220-volt inductive circuit.—The curves of inductive pressure rise are irregular, and show the highest voltages in the series.

Fig. 8 P.—Comparing this with Fig. 8 C for copper and Fig. 8 G for tin in enclosed fuses, it will be seen that copper breaks the circuit more quickly than either of these two.

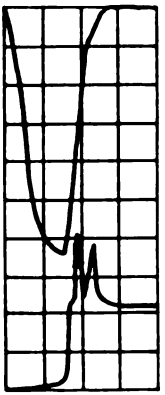
Variation of the Minimum No-arc Length with the Inductance of the Circuit.—A consideration of the oscillograms referred to above shows that inductive pressure rises of as much as four times the circuit pressure may be met with in moderately inductive circuits. In the experiments with the oscillograph a choking coil of very low resistance was inserted in series with the fuse; the value of the inductance was 0·023 henry with the normal fusing current (27 amperes) of the fuses under test flowing in the circuit. The value of the inductance would, of course, be less with short-circuit current flowing on account of the saturation of the core of the choking coil.



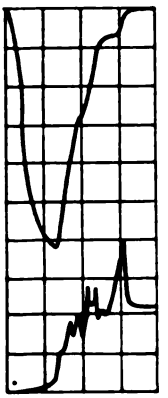
K


0
100
200
300
Amps.
Volts.
400
300
200
100
0
0
0·04
0·08
0·12 second.

N



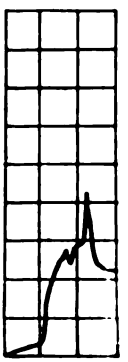
L



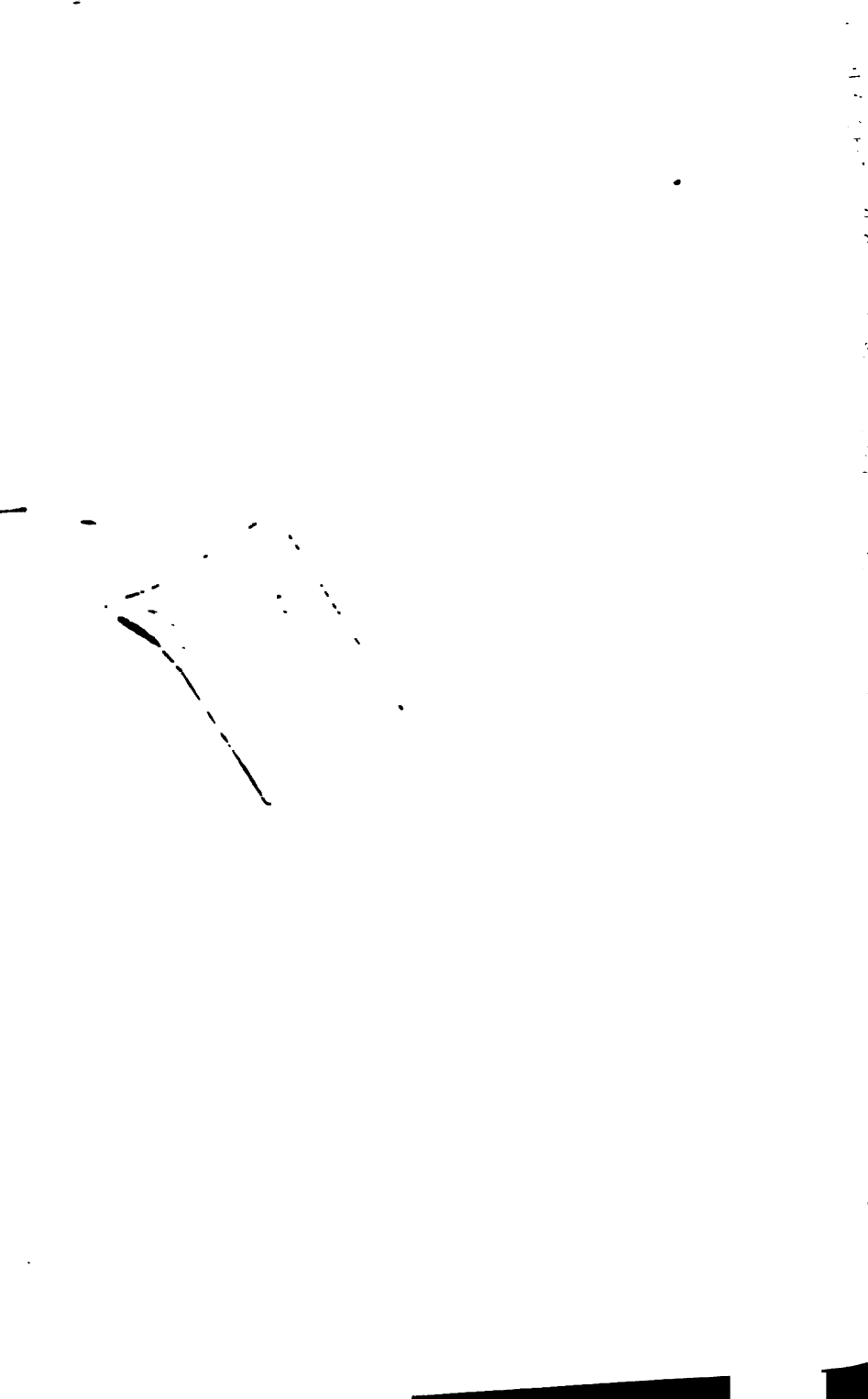
O


Volts.
300
200
100
0

M



P



In practice inductive circuits will be met with in connection with series motors, arc lamps, and in certain cases of breakdown of motor fields.

The following values for inductance are from measurements by Mr. J. Davies on plant in the School of Technology, Manchester :—

Series field of 25-H.P. Dick Kerr tram motor... = 0·0780 henry.
Shunt field of 15-H.P. 4-pole Kolben motor coils in series = 3·6700 „
Arc lamp, series type = 0·0040 „
Continuous-current machine armature of 15 k.w. = 0·0002 „

It was found that the minimum no-arc length was increased on circuits with an inductance of 0·023 henry as against circuits in which the inductance was only that due to that of the generator and leads; the results are shown in Fig. 4. On non-inductive circuits the tests showed comparatively small voltage rises, and these were of short duration.

Where present, the voltage rise occurs at two definite periods: first, when the current commences to fall, and secondly, when it ceases. The tests were carried out on circuits of moderate inductance, because the pressure curves thus obtained gave more information as to the working of the fuse than with non-inductive circuits.

Variation of the Minimum No-arc Length with the Disposition of the Cables to the Fuse Terminals.—In order to test the magnetic blow-out effect obtainable from the circuit conductors, the leads to the fuse terminals were bent through a right angle as shown in Fig. 9.

It was found with this arrangement that the minimum no-arc length for open-type fuses could be very considerably reduced. For instance, with a 27-ampere copper fuse on a 220-volt circuit with leads bent up for a distance D = 4 in., the minimum no-arc length was 0·7 in., as against a length of 3·6 in. with the circuit cables entering the terminals in the ordinary way. Short-circuit current = 33 × N.F.C. The length was not materially increased with the bend in the leads reduced to D = 1 in., and even when an arc was formed it was of short duration and little damage was done to the terminals. This magnetic blow-out arrangement might well be taken advantage of in practice, as has already unwittingly been done with some forms of knife-blade terminals, and terminals in which the cables enter from the back in contradistinction to the sides.

Photographs of fuses blowing with magnetic blow-out arrangements are shown in Fig. 9 A. They should be compared with the photographs shown in Fig. 6, which are without such an arrangement. This comparison shows that in the photographs with the magnetic blow-out, the arc and vapour were dissipated so rapidly as to have prevented action on the plate.

In order to obtain more direct evidence of the magnetic blow-out effect, a number of oscillograms were obtained for open- and enclosed-type fuses when blown in a magnetic field (*a*) at right angles to the

length of the fuse, (*b*) parallel to the length of the fuse. A selection of these is given in Fig. 10, which shows the relative effects of these two dispositions for an open-type fuse when blown inside a field-coil spool which was separately excited.

A longitudinal field was next produced by winding the lead to the fuse into a coil with a few turns through which the fuse passed; the results are given in Fig. 11. A consideration of this figure shows that the magnetic field is of considerable use in extinguishing the arc.

Further experiments were made with the fuse wire doubled back upon itself for an inch, the legs of the loop being lapped with asbestos

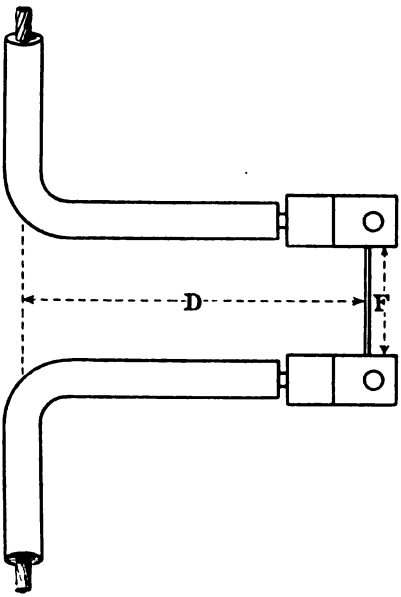


FIG. 9.—Arrangement of Leads to Fuse for Magnetic Blow-out Effect.

D. Distance through which leads are bent up at right angles.
F. Fuse length.

paper. The oscillograms are given in Fig. 12. For the photograph of a fuse of this form when blowing see Fig. 9 B. In this case, however, the legs of the loop were separated by a piece of asbestos millboard. Extending the experiments on the magnetic blow-out effect to enclosed fuses, a small permanent magnet was first employed with but little effect.

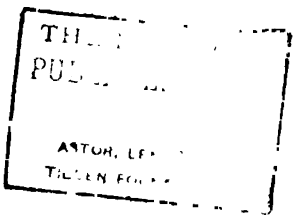
A solenoid was then arranged in series with the fuse (*a*) with lateral field, (*b*) with longitudinal field; this resulted in both cases in the quicker rupture of the arc and an increased inductive pressure rise. The results are given in Fig. 13.



FIG. 9A.



FIG. 9B.


ASTOR, LE
TILDEN FO

A separately excited field coil gave similar results with both lateral and horizontal fields.

Variation of No-arc Length with the Mass of the Terminals.—A consideration of Table III. shows that the minimum no-arc length diminishes as the terminals are increased in size, and this effect is greatest with small fuses.

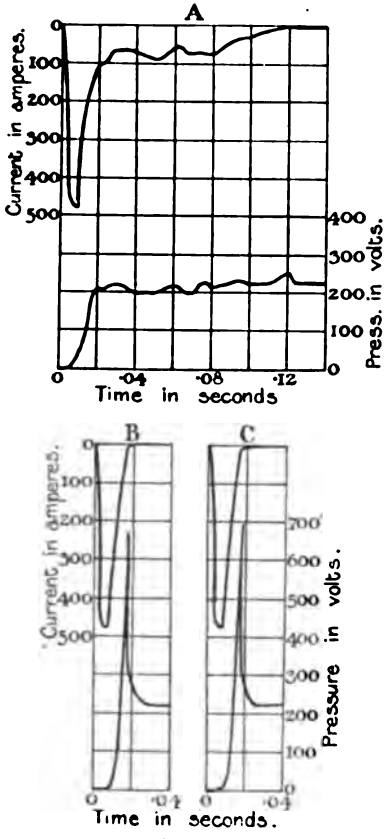


Fig. 10.—Oscillograms of Magnetic Blow-out Effect with Copper Fuses of Open Type on 220-volt Circuit. Fuses placed in a separately excited Field-coil Spool.

A. No magnetic field.
B. Lateral magnetic field.
C. Longitudinal magnetic field.
N.F.C. = 20 amperes.

This effect is probably not so much due to the cooling of the ends of the fuse by conduction, which for short-circuit currents of 33 × N.F.C. may be considered negligible, the whole length of wire being almost instantly disrupted, as to the cooling of the arc vapour by the terminals. This cooling, taking place along a transverse section of

the arc, introduces at each end a small section of high resistance which breaks down the arc.

Variation of No-arc Length in Enclosed Fuses, with the Character and Disposition of the Filling.—In considering the no-arc length for enclosed

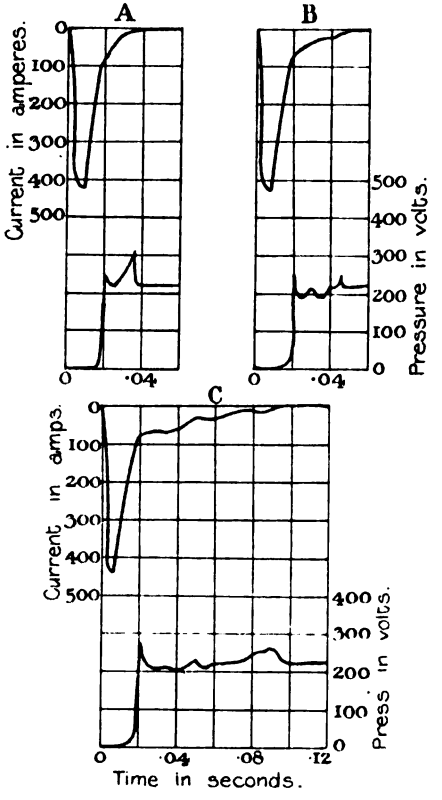


FIG. 11.—Oscillograms of Open-type Copper Fuse on 220-volt Circuit blown in a Longitudinal Magnetic Field, produced by forming the Lead to the Fuse into a Coil, through which the Fuse passed.

A. Coil of 10 turns.
B. Coil of 20 turns.
C. No magnetic field. The 20-turn coil was retained in the circuit, but removed from the fuse.
N.F.C. = 20 amperes.

fuses, the following factors have to be taken into account in connection with the filling material :—

(*a*) The formation of tubes at high temperatures.
(*b*) The specific heat and thermal conductivity of the filling.
(*c*) The degree of fineness of the particles.
(*d*) The effect of tight or loose packing.
(*e*) The effect of moisture in the filling.

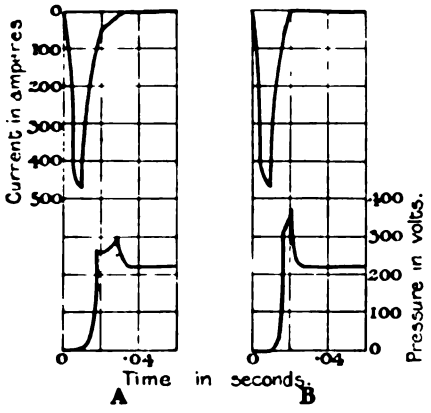


FIG. 12.—Oscillograms of Magnetic Effect obtained by Bending the Fuse Wire.

A. Straight wire.
B. Wire bent back on itself for 1 in.

N.F.C. = 20 amperes.

In each case the wire was lapped round with asbestos paper and blown on a 220-volt induction circuit.

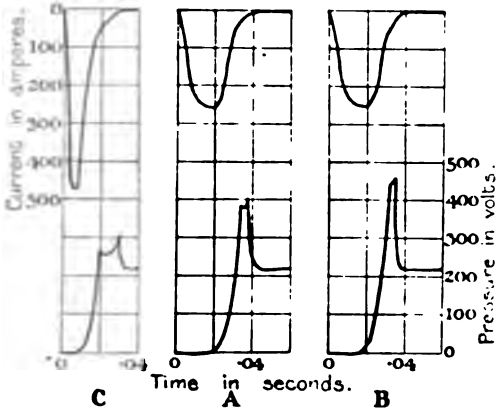


FIG. 13.—Oscillograms of Enclosed-type Fuse blown in a Magnetic Field produced by forming the Lead to the Fuse into a Solenoid.

A. Lateral magnetic field.
B. Longitudinal magnetic field.
C. No magnetic blow-out; extra length of lead forming the solenoid removed from the circuit.

In each case the fuse was of copper. N.F.C. = 20 amperes on a 220-volt circuit. Inductance, 0·023 henry.

The Formation of Tubes in the Filling at High Temperatures.—The formation of a slag tube around the fuse on disruption has already been referred to (see Fig. 1); the formation of such tubes would seem to depend on the character of the filling employed, and to some extent on the character of the fuse metal. In general, silicious fillings favour the formation of these tubes, whereas cretaceous or chalky fillings do not.

Metals with a high melting-point would at first sight seem to favour this formation, but it must be borne in mind that although the melting-point of a metal such as tin is low, yet the temperature of the arc following disruption may be, and probably is, as high as with metals of a higher melting-point.

The results given in Table VII. are from experiments with various fillings in use commercially.

TABLE VII.

Formation of Tubes in the Filling of Enclosed Fuses on Disruption.

Filling.	Remarks.
Calais sand	Forms tubes.
Coarse emery	Slight formation of tubes.
Fine emery...	" " " "
Trent sand	Does not form tubes.
Pumice	Forms tubes.
Chalk	Does not form tubes.
Crushed limestone	Very slight formation of tubes.

Specific Heat and Thermal Conductivity of the Filling.—Apart from the formation of tubes and the absorption of moisture by the filling, the chief characteristics which differentiate the various materials used for fillings are the degree of fineness of the particles and the degree of tightness of the packing; the specific heat and thermal conductivity of the filling only influence the results indirectly, in that they affect the normal fusing current of the fuse.

The normal fusing current for a given fuse is greater when enclosed and surrounded by a filling than when free in air from terminal to terminal. Experiments with a copper wire (N.F.C. in air, 20 amperes) illustrating this point are given in Table VIII.

TABLE VIII.

Increase in Normal Fusing Current for Fuses enclosed in a Porcelain Tube $\frac{3}{8}$-in. Internal Diameter with various Fillings.

Nature of Filling.	Normal Fusing Current in Amperes.
Air (open fuse)	20
Trent sand (loosely packed)	22
Trent sand (tightly packed)	25
Calais sand	30

In order to compare the rate of conduction of heat through the various fillings, the following experiments were made: A glass beaker was filled with a sample of the filling to be tested, and a thermometer was embedded in the centre of the mass of powder; the beaker was then surrounded with water, which was kept gently boiling. A curve connecting time and temperature indicated by the thermometer was then obtained for each filling. These curves are given in Fig. 14; they do not exactly represent the relative thermal conductivities of the powders, but depend also upon their specific heats.

A consideration of these curves and of Table VIII. shows that the normal fusing currents increase relatively in the same way as the rates of conduction of heat through the fillings. In order to see if the diameter of the enclosing tube and the quantity of filling employed exerted any considerable effect on the normal fusing current, tubes

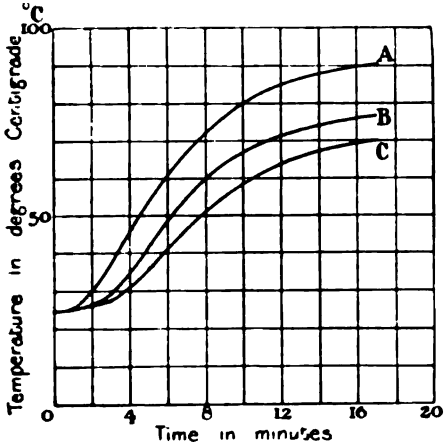


FIG. 14.—Curves showing the Rise of Temperature of a Thermometer embedded in various Materials employed for the Fillings of Enclosed Fuses, the External Temperature being 100° C. in each case.

A. Calais sand.
B. Trent sand (packed tightly).
C. Trent sand (packed loosely).

of ⅜ in., ½ in., and 1¼ in. internal diameter were employed, and in each case for a copper wire with a Calais sand filling the fusing current was found to be 30 amperes.

The above results would seem to indicate that it is only a comparatively thin layer of filling round the fuse which exerts any considerable influence on the fusing current, and further, that this effect is due chiefly to the conductivity of the filling for heat.

It is probable that with tubes of very small diameter and with a small amount of filling the normal fusing current would not be increased so much as in cases given in Table VIII. Three experi-

ments with a No. 27 S.W.G. copper wire, N.F.C. in air 20 amperes, when passed through a clay tobacco-pipe stem, gave a mean result of N.F.C. = 28 amperes. The same size wire when passed through a braided asbestos tube had an N.F.C. = 22 amperes when the texture of the braiding was open, and 25 amperes when the texture was very close.

Variation of No-arc Length for Enclosed Fuses with the Degree of Fineness of the Filling.—The effect of the size of the particles of the filling on the duration of the arc is shown in Fig. 15. It will be seen that the more finely the material of the filling is divided the more quickly is the arc extinguished, and consequently the pressure rise on an inductive circuit would be high.

This result is supported by a large number of oscillograms with various powders, both coarse and fine. The fine powders seem to be

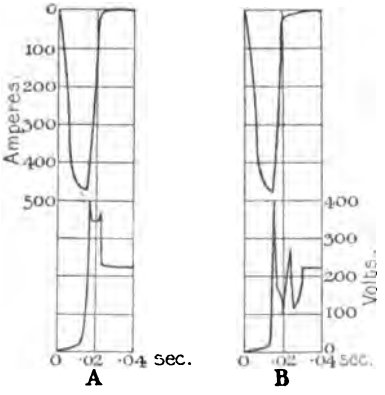


FIG. 15.—Oscillograms showing the Effect of the Size of Particles of the Filling on the Behaviour of an Enclosed Fuse.

A. Powder passed through mesh 50 to the inch.
B. Powder passed through mesh 10 to the inch, retained on mesh 30 to the inch.
No. 27 copper wire on a 220-volt inductive circuit. Crushed limestone filling.

more effective in repressing the arc than the coarse ones, owing to their interstices being smaller and less air being included. This effect is linked with the degree of tightness with which the filling is packed: in the oscillograph experiments, the results of which are given in Fig. 15, the powders were not packed into the tubes, but merely shaken down lightly into position. With the coarse filling the circuit was sometimes opened satisfactorily and sometimes irregularly.

Effect of Tight and Loose Packing of the Filling on the Minimum No-arc Length for Enclosed Fuses.—Experiments were carried out with fillings of various degrees of fineness packed both tightly and loosely, and it was found that with fine powders the minimum no-arc length was shorter for both tight and loose packing than with coarse powders.

This points to the presence of air spaces in the filling, due to the size of the particles of the filling being large, as having an adverse influence on the minimum no-arc length, since the tightness of the packing has but little influence in reducing the air spaces with coarse powders. Results illustrating this point are given in Table IX.

TABLE IX.

Effect of Tight and Loose Packing for Fillings of Enclosed Copper Fuses on 220-volt Inductive Circuit.

N.F.C. of Copper Fuse in Air.	Minimum No-arc Length in Inches.		
	Calais Sand.	Trent Sand.	
		Loosely Packed.	Tightly Packed.
27 amperes	2·0 in.	1·4 in.	0·8 in.
43 „	2·2 „	1·4 „	1·0 „

With fine powders loosely packed there is a good deal of noise on disruption if the jacket is not hermetically sealed, and the filling is much blown about and some of it is compressed by the explosion against the inside of the tube. Loose fillings are therefore not to be recommended; and further, when used vertically, as is nearly always the case, the filling will gradually settle together more closely, leaving a portion of the wire at the top end of the fuse exposed.

In order further to investigate the influence of tight packing, a series of experiments was carried out with fuse wires set in plaster of Paris. This practically amounts to a fuse with a very tightly packed filling; such fuses give a quick break, with a consequent high inductive pressure rise on inductive circuits. Oscillograms on this point are given in Fig. 7. In general, these fuses blow very quietly, provided that the plaster covering does not crack or rupture; when this occurs bad arcing frequently results, and a loud report is produced.

It is essential that the whole length of the fuse wire should be embedded in the plaster; this can be effected by soldering the fuse to stout copper connecting wires, one end of the wire being connected to the fuse contacts, while the other is embedded in the plaster. A containing envelope or jacket, even if only of slight mechanical strength, is essential for plaster fillings.

Effect of Moisture in the Filling.—The presence of moisture in the filling may affect the fuse in the following ways:—

(*a*) By actual combination with the filling material, causing it to set or otherwise altering its condition, *e.g.*, plaster of Paris.

(*b*) A filling which has been moist may on subsequent drying become more or less coherent or caked.

(*c*) An absorbent filling or a hygroscopic one will affect the arc disruption by cooling it, but may give rise to considerable pressure due to the generation of steam. It will also give rise to electrolytic corrosion in course of time.

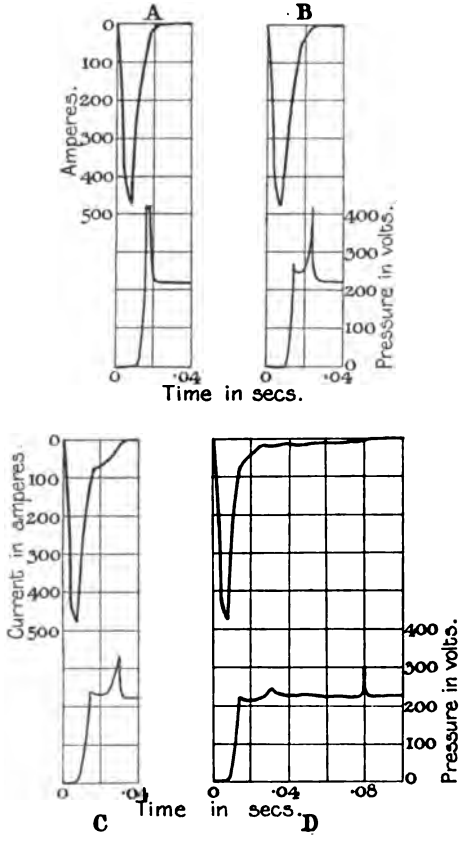


FIG. 16.—Oscillograms of Enclosed Fuse on 220-volt Inductive Circuit.

A. 0·5 per cent.
B. 3·7 per cent.
C. 12·8 per cent.
D. Same as (*c*), but arc persisted longer. Given to show the characteristic voltage rise at break when powder is moist.

Copper wire, No. 27. Calais sand filling with various amounts of moisture.

(*d*) The filling may be normally dry, the liquid being held in a special vessel or container, and only liberated on a short circuit taking place when it extinguishes the arc.

With enclosed fuses in general the jacket affords considerable protection from moisture, and the filling materials usually employed do not cake or cohere. Moisture in the filling, however, is not unusually

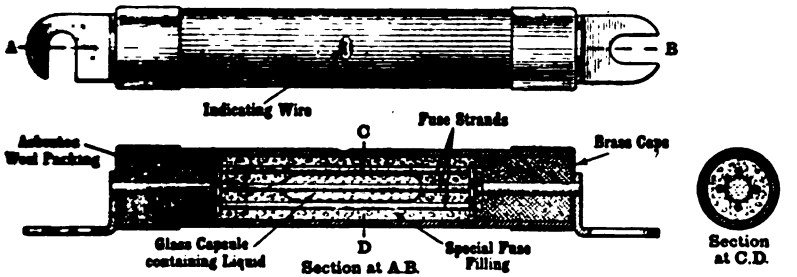


FIG. 17.—Construction of "Koolark" Fuse.
(Reproduced by kind permission of the *Electrician* Publishing Co.)

present in commercial forms of fuses in red fibre jackets, as it exudes on tests when the fuse becomes hot. The closing of the vent holes of such fuses with a disc of glazed paper does not seem to be a very

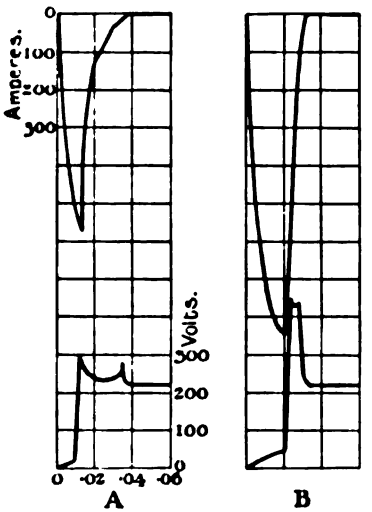


FIG. 18.—Oscillograms of "Koolark" Fuse on 220-volt Circuit.

A. Without glass tube.
B. With glass tube.
Short-circuit current = 33 × N.F.C.

efficient means of preventing the ingress of moisture in damp situations.

Experiments were made with Calais sand as representing a siliceous non-absorptive filling. Oscillograms of a copper fuse on a 220-volt

inductive circuit with fillings containing up to 12·8 per cent. of water by weight are given in Fig. 16.

A consideration of these would seem to show that no very marked effect is produced on the action of the fuse by moderate amounts of moisture in the filling, but that when in excess—with 12·8 per cent. of water the filling was almost "sloppy"—it produces irregularity of action in the fuse.

Experiments were then made with a filling of Trent sand; this is much finer in texture than Calais sand, and absorbs water freely, ultimately forming a mud. As the percentage of moisture in the Trent sand was increased, the action of the fuse became irregular, but with the moderately wet sand tightly packed a quick break and high voltage rise resulted. In this series of oscillograms of fuses in Trent sand, which are not reproduced here, the arc was broken very quickly, due probably to its being cooled by the evaporation of the water. This point is of interest in connection with a type of fuse recently placed upon the market in which a special liquid enclosed in a small glass tube is disseminated throughout the filling when the fuse is subjected to a short circuit. When the fuse blows with a moderate overload the glass tube is not broken and the filling remains dry.

The construction of this fuse is shown in Fig. 17, which is an illustration of E. B. Schattner's enclosed fuse known as the "Koolark" fuse. Oscillograms showing its behaviour on short circuit (*a*) without the glass tube; (*b*) with the glass tube are shown in Fig. 18.

Although moisture in the filling may not very seriously affect the action of the fuse as far as the suppression of the arc is concerned, its presence in enclosed fuses is not at all desirable, as it would certainly lead to corrosion and electrolytic troubles, particularly if a contact difference of potential exist between the fuse and the wire or lug connecting it to the fuse contacts.

VII. The Time Element.

Experiments were made to determine the relative time element for fuses of a given metal having the same cross-sectional area in cut-outs of open and enclosed types.

Expressing the overload as a percentage of the normal fusing current, it was found that enclosing the fuse increases the time element. This is particularly noticeable for small overloads, which allow of sufficient time for the conveyance of heat to the filling before the fuse is disrupted. For large overloads the difference in time element is not so marked, since the time is too short for much heat to be conveyed to the filling. Since the normal fusing current for an enclosed fuse is considerably greater than that of the same fuse when free in air from terminal to terminal, and since we are expressing the overload as a percentage of the normal fusing current, it is on this basis conceivable that an enclosed fuse would operate more quickly than an open one of the same cross-sectional area owing to the larger current taken by the enclosed fuse. This is found to be the case, and curves illustrating it

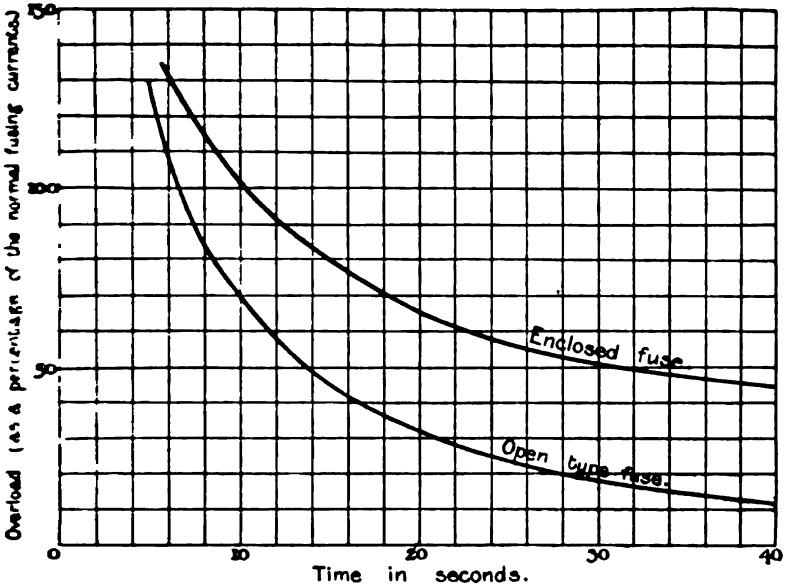


FIG 19.—Relative Time Elements for Open and Enclosed Fuses.

Tin wire, No. 17 S.W.G.
N.F.C. in air = 20 amperes.
N.F.C. in Calais sand = 27·5 amperes.
Internal diameter of fibre jacket, 0·5 in.
External diameter of fibre jacket, 0·75 in.

Overloads reckoned as a percentage of the respective normal fusing currents. Fuses initially cold.

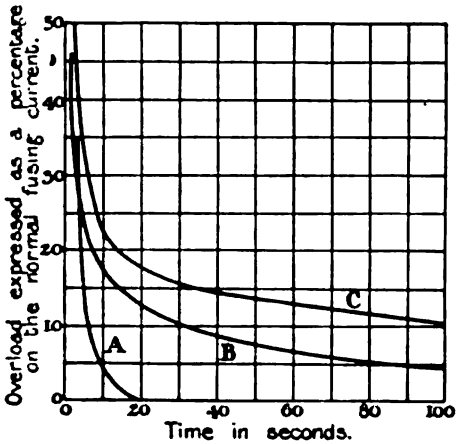


FIG. 20.—Relative Time Elements of Fuses with Copper Wire No. 27 S.W.G. Fuses initially cold.

A. Free in air.
B. Enclosed with Calais sand filling.
C. Enclosed with Trent sand filling.

are given in Fig. 19 for tin. This effect is also shown in Fig. 20 for copper. A consideration of this figure shows that for a given size of copper wire there is a good deal of difference in the normal fusing current for the various kinds of filling. The curves connecting time and percentage overload, however, lie well together, but they are not placed in the same order as that of the normal fusing currents.

This is due to the filling not only influencing the time taken to blow the fuse with a given current, but also the normal fusing current, and consequently the percentage overload, which is based upon it; and it is evident that these two effects tend to neutralise each other as far as regards position on the curve.

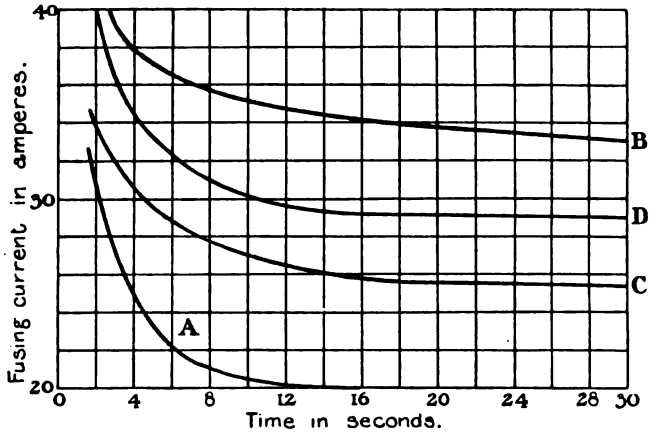


FIG. 21.—Relative Time Elements for Copper Wires of same Diameter (No. 27 S.W.G.) plotted against Fusing Currents in Amperes for Open and Enclosed Fuses with various Fillings. Fuses initially cold.

A. Open-type fuse.
B. Enclosed fuse Calais sand filling.
C. Enclosed fuse Trent sand filling (loosely packed).
D. Enclosed fuse Trent sand filling (tightly packed).

This point is emphasised by plotting curves under the same conditions as above, but connecting time of fusion and current in amperes as in Fig. 21. It will be seen that the curves now lie much further apart, and also that they are placed in the same order as the thermal conductivities of the fillings given in Fig. 14.

Relative Time Element for Open and Enclosed Fuses with the same Normal Fusing Current.—A copper wire in an enclosed cut-out with Calais sand filling was found to have a normal fusing current of 30 amperes. A second copper wire was then taken and drawn down so as to have as nearly as possible this normal fusing current in air.

The time elements for these two wires were then found for various overloads, and the results are shown graphically in Fig. 23, where the

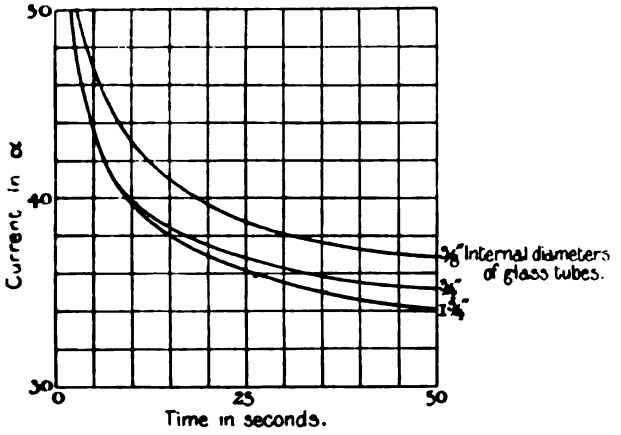


FIG. 22.—Curves connecting Current and Time of Fusion for a No. 27 S.W.G. Copper Fuse in Calais Sand in Glass Tubes of various Internal Diameters and the same Thickness of Wall. Fuses initially cold.

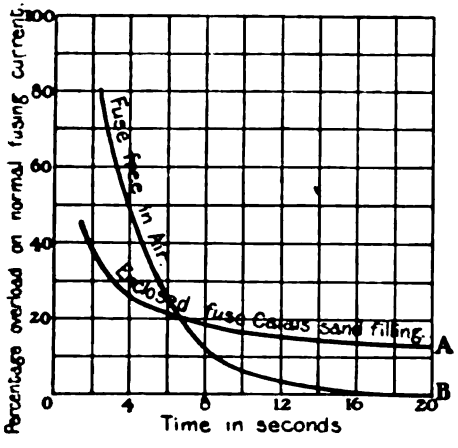


FIG. 23.—Relative Time Elements for Copper Wires with approximately the same N.F.C. in Air and in Calais Sand. Fuses initially cold.

A. N.F.C. in air = 32 amperes.
B. N.F.C. in Calais sand = 30 amperes.

crossing of the curves owing to the smaller amount of metal in the enclosed fuse is clearly shown.

Temperature Rise for Jackets of Enclosed Fuses.

The chief factor which determines the temperature rise of an enclosed fuse as measured by the external temperature attained by the jacket is the melting-point of the metal employed, metals with high melting-points on continuous overloads giving a higher external temperature on a jacket of given diameter than those of greater fusibility.

In Fig. 24 curves are given of the temperatures attained by the outside surfaces of red fibre tubes with Calais sand filling with tin, zinc, and copper as the fuse metals when run with various percentages of their fusing currents.

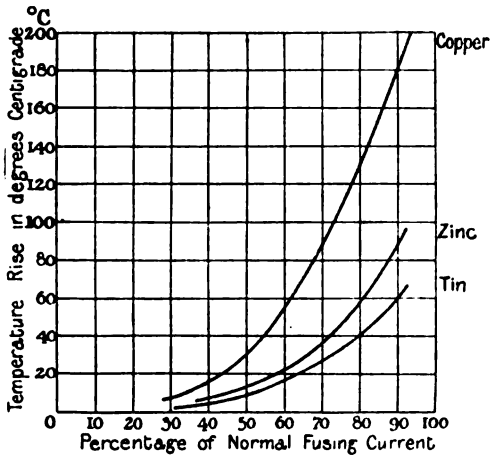


Fig. 24.—External Temperature Rise for Fuses of Different Metals enclosed in Red Fibre Tubes, ½-in. Internal and ⅝-in. External Diameter, and 2·4 in. long.

Normal fusing currents when enclosed :—
Tin, 28 amperes.
Zinc, 26 amperes.
Copper, 30 amperes.
The filling in each case was Calais sand.

A consideration of this figure shows that copper gives the highest temperature-rise, but that when running at 50 per cent. of its normal fusing current (*i.e.*, when rated to blow with 100 per cent. overload) the temperature attained even at full load is not excessive, and that when running at the rating given in the Institution Wiring Rules, namely, 200 per cent. overload for fusion—the external temperature of the jacket does not differ very materially from that obtaining with zinc and tin.

The temperatures in each case were determined by means of a platinum wire spiral wound closely over the jacket. With regard to the temperature of the inside of the jacket a number of determinations were made which showed that the inside temperatures were not

greatly in excess of those obtaining outside except in the case of copper.

In these experiments the platinum spiral which was used as a thermometer was placed as close as possible to the inner wall of the jacket, but the results obtained were rather variable owing to the liability of the platinum spiral to displacement when packing the filling into the cartridge.

Temperature Rise and Diameter of Jacket.—The temperature rise of the jacket is a function of the diameter of the cartridge employed; the smaller the latter is the higher will be the external temperature of the jacket. This effect is illustrated by the results shown in Fig. 25, which

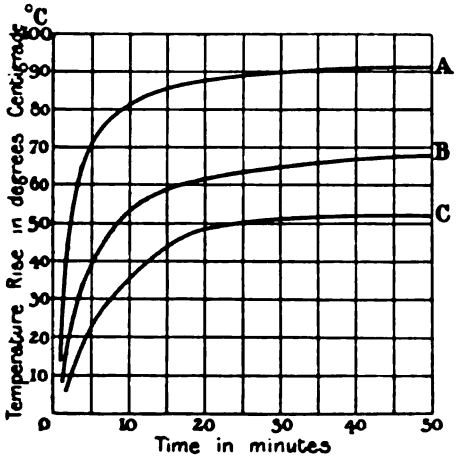


FIG. 25.—Relative External Temperature Rise with a No. 27 S.W.G. Copper Wire with Calais Sand Filling (N.F.C. enclosed = 30 Amperes), enclosed in Red Fibre Tubes of the following Diameters, with a steady Current of 20 Amperes passing through the Fuse:—

Red Fibre Tube.	Internal Diameter in Inches.	External Diameter in Inches.
A	0.12	0·25
B	0·25	0·45
C	0·5	0·75

gives the temperature rise for a copper fuse (N.F.C. = 30 amperes) with a Calais sand fillings and red fibre jackets of various diameters.

Temperature-rise and Material of Filling.—Experiments on the effect of the character of the filling material on the temperature rise of the jacket were made with two similar fuses in fibre cases ½ in. in internal diameter.

In the one case Trent sand, which is a comparatively poor conductor of heat (see Fig. 14), was employed as the filling, while in the other Calais sand, which is a comparatively good conductor of heat, was used.

Curves connecting the temperature rise of the jacket with these two

fillings and the percentage of the fusing current are given in Fig. 26. From the point of view of low-jacket temperatures, fillings with a low heat conductivity are desirable.

Effect of Jacket Material on the External Temperature.—In order to determine the effect of the jacket material on the external temperature attained similar tubes of red fibre and of brass were employed as jackets. In order that the temperature of the metal tube could be measured by means of a platinum spiral both jackets were covered with a thin layer of asbestos paper. The difference in temperature rise with a given load in the two cases was found to be very slight, the external temperature of the metal tube being slightly higher than that of the fibre tube.

Measurements of the temperature of the inside surface of the jacket were found to be unreliable for the reason already referred to.

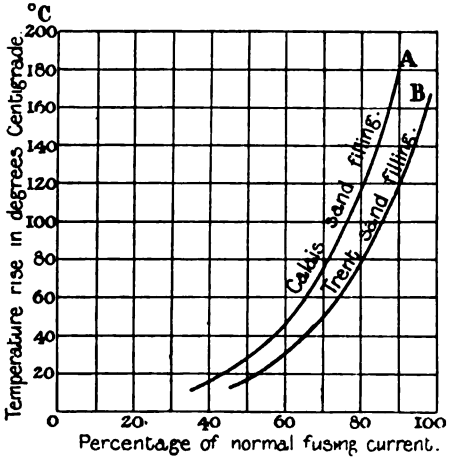


FIG. 26.—Relative External Temperature Rise with a No. 27 S.W.G. Copper Wire (N.F.C. enclosed = 30 Amperes), enclosed in a Red Fibre Jacket, ½-in. Internal Diameter, with the following Fillings :—

A. Calais sand (relatively good conductor of heat).
B. Trent sand (relatively poor conductor of heat).

Deterioration of Red Fibre at High Temperatures.—A short series of experiments were carried out to determine the effect of high temperatures on red and black fibre, with the following results :—

1. Red and black fibre heated at 180° C.: A slight amount of moisture came off in the form of steam, but there was no charring.
2. Red and black fibre heated to 210° C. for forty-five minutes: The specimens got very dry but were not apparently charred.
3. Red and black fibre heated to 240° C.: The specimens first became brittle and then charred.

With material composed largely of vegetable fibre brittleness and charring may be induced by exposing it for a long period of time to temperatures considerably lower than those referred to.

With fibre tubes charring frequently occurs as the result of a short circuit, and even if it does not show on the outside of the jacket an examination will frequently show that the inside surface has been blistered.

Note on the Rating of Fuses.

A good deal of confusion exists as to the rating of fuses owing to the variety of conditions on which this rating may be based, the following suggestions are therefore put forward with a view of eliciting discussion on this point and of possibly clearing away some misconceptions.

Since the various circuits met with in practice are capable of withstanding without injury definite amounts of overload, this fact would seem to afford a sound basis for fixing the limit for the normal fusing current of the fuse employed to protect the circuit.

The fuse may with advantage be designated by the normal full-load current of the circuit on which it is to be employed. Thus, a "50-ampere fuse" would mean a fuse for the protection of a circuit the normal full-load current of which is 50 amperes.

The fuse may be designed to blow with any current greater than this that may be desired.

The fuse selected should be such that when carrying continuously a current slightly less than its normal fusing current no injury to the circuit due to overheating should result.

As an example of this method of procedure we have collated the experimental results recently obtained by Kennelly and Shepard* for

Table X.

Temperature Rise of Rubber-covered Wire in Wood Casing Nailed to the Floor from the Experiments of Kennelly and Shepard.

Diameter of Wire in Inches.	Initial Temperature in °C.	Temperature Rise in °C. to reach I.E.E. Limit for Rubber of 54·4° C.	A Current in Amperes to reach I.E.E. Temperature Limit of 54·4° C.	B I.E.E. Maximum Permissible Load in Amperes. $C = 2{\cdot}6\,A^{0.82}$.	Rating of Fuse for Sensitiveness A B
0·050	21·1	33·3	20·0	4·52	4·43
0·064	19·1	35·3	26·5	6·78	3·91
0·080	19·9	34·5	33·5	9·77	3·43
0·102	19·0	35·4	46·5	14·50	3·19
0·128	19·0	35·4	62·0	21·10	2·94

* "Heating of Copper Wires," *Transactions of the American Institute of Electrical Engineers*, vol. 26, 1907.

the heating of copper conductors insulated with rubber and laid in wood casing, with the regulations as to temperature rise and maximum current permissible contained in the 1907 edition of the Wiring Rules issued by this Institution. The results are given in Table X. The wires in each case took about thirty minutes to attain to their maximum temperatures with a given load.

Assuming in a given case that we decide to work with a factor of safety of 2 on the I.E.E. limit, column A Table X., and to take their figure for the permissible normal full-load current of the circuit, we can then express the normal fusing current of the fuse required as a multiple of the normal full-load current of the circuit. Thus for a wire 0·050 in. diameter and a full-load circuit current of 4·52 amperes (see Table X.)—

A = Current required to attain maximum permissible temperature 20·00 amperes.
B = Permissible full load current (I.E.E)... 4·52 „

$$\text{Normal fusing current} = B \times \frac{A}{B} \times \frac{1}{2}.$$

$$= B \times \frac{20}{4{\cdot}52} \times \frac{1}{2}$$

$$= 4{\cdot}5 \times 2{\cdot}2.$$

The figure obtained by dividing the maximum permissible overload by the full-load current of the circuit represents the "sensitiveness," or, more correctly speaking, the insensitiveness of the fuse.

It should not be a difficult matter to determine the suitable sensitiveness for fuses required for the protection of arc lamp, heating, or motor circuits.

The normal fusing current for a fuse should be determined by direct experiments. A curve should be plotted for fusing currents on a time base, taking in the first instance currents slightly in excess of the normal fusing current and then reducing the current and noting when the current curve becomes parallel to the axis of time.

This procedure is a little laborious but is absolutely necessary in view of the length of time which large enclosed fuses take to attain a steady temperature.

This point is illustrated by Figs. 27 and 28 for American enclosed fuses given by Dean Harvey* in a recent number of *The Electric Journal.*

A consideration of Fig. 27 shows that in order to obtain a correct value for the normal fusing current of the 400-ampere enclosed fuse (Fig. 29) a longer time than that shown should be taken.

The normal fusing current for a given line of fuses should be obtained by the manufacturers or by an independent testing authority and the fuses should be marked with their rating before being placed on the market.

* "Fuses," *The Electric Journal*, vol. 3, p. 159, 1906.

In the United States the regulations given in the National Electric Code (1905) as regards rating are as follows:—

Open-type Fuses.—Must be stamped with about 80 per cent. of the maximum current which they can carry indefinitely, thus allowing about 25 per cent. overload before the fuse melts.

NOTE: With naked open fuses of ordinary shapes and with not over 500 amperes capacity the *minimum* current which will melt them in about five minutes may be safely taken as the melting-point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary. This data is given to facilitate testing.

Enclosed Fuses.—With the surrounding atmosphere at a temperature of 75° F. they must carry indefinitely a current 10 per cent. greater than that at which they are rated, and a current 25 per

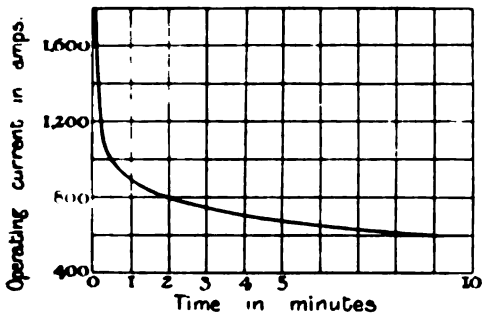


FIG. 27 (Dean Harvey).—Curve showing Overload Capacity of 500-volt, 400-ampere National Standard Enclosed Fuse.

cent. greater than the rating, they must open the circuit without reaching a temperature which will injure the fuse-tube or terminals of the fuse block. With a current 50 per cent. greater than the rating, and at a room temperature of 75° F., the fuses starting cold must blow within the following times:—

Capacity of Fuse.				Time.
0–30	amperes	...	...	30 seconds.
31–60	,,	...	...	1 minute.
61–100	,,	...	...	2 minutes.
101–200	,,	...	...	4 ,,
201–400	,,	...	...	8 ,,
401–600	,,	...	...	10 ,,

NOTE ON THE TIME ELEMENT OF FUSES.

We have seen that the rating of a fuse may be determined from a consideration of the permissible temperature rise in the circuit to be protected; the time element of a fuse is, however, dependent upon

the heat capacity of the fuse and its immediate surroundings. The time element of a fuse may be defined as *the time lapse necessary for the heating of the fuse from the cold state to the fusing-point with a given overload.*

The heat capacity of a fuse will be proportional to the mass heated, the average specific heat of the mass, and the temperature rise from the cold state to the melting-point.

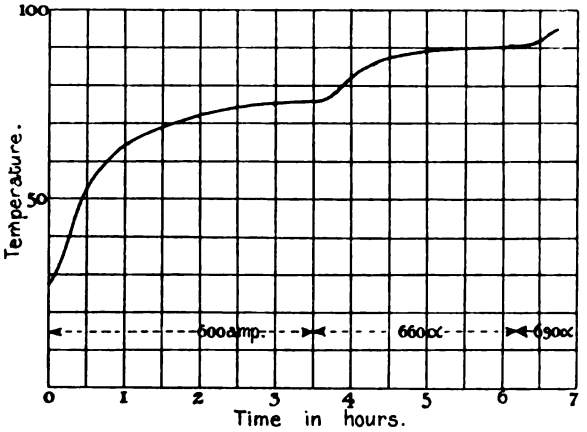


FIG. 28 (Dean Harvey).—Curve showing Rating Test of 250-volt, 600-ampere National Standard Enclosed Fuse.

With enclosed fuses this heat capacity will vary with the character of the overload, since with large overloads there is insufficient time for the conduction of heat from the fuse to the filling, and the temperature rise of the latter is consequently small.

Apart from the above consideration the time required for reaching the fusing-point is for a given fuse inversely proportional to the square of the current.

The heat capacity of a fuse may be varied by changes in :—

(*a*) The fuse metal.
(*b*) The shape of the fuse.
(*c*) The environment of the fuse.

These variations may be made use of for altering the time element of a fuse for a fixed rating to a considerable extent. The greatest difference in time element will be between an open fuse of copper and an enclosed fuse of a sluggish metal such as tin or zinc ; Fig. 29 shows the relative time elements of such fuses with a fusing current of about 250 amperes. The results given are collated from Meyer's * experiments for copper fuses and from Edward Taylor's † tests on enclosed

* *Zur Theorie der Abschmelzsicherungen*, R. Oldenbourg, Berlin, 1907.
† *Street Railway Journal*, vol. 25, p. 548, 1905.

fuses. A consideration of Fig. 29 shows that with an overload of 50 per cent. the time elements for enclosed and open fuses are as 4 to 1 and at 25 per cent. overload as 7 to 1.

The above considerations hold for fuses of the same rating; the time element for a given type of fuse will, of course, vary with the capacity of the fuse.

It is desirable that a definite basis for reference should be established for the time element, and we would suggest that the time element of a fuse should be defined as follows:—

The time element of a fuse is that time which is required to heat up the fuse from the cold state until it blows with an overload of 50 *per cent. reckoned on the normal fusing current of the fuse.*

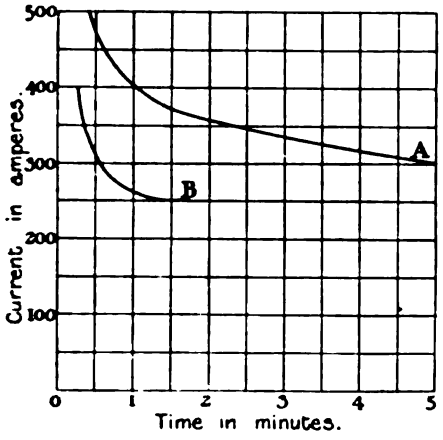


FIG. 29.—Relative Time Elements of Enclosed and Open-type Fuses.

N.F.C. about 250 amperes.
A. Zinc enclosed type.
B. Copper open type.

For large-size enclosed fuses the time element as defined above would be of the order of four or five minutes. For metals with low melting-points the time element will be decreased if the external temperature is high.

NOTE ON SHORT-CIRCUIT CURRENTS.

It is evident that the position of a fuse on a system with reference to the generators will largely determine the character of the current rush on short circuit; it would therefore seem advisable that fuses should be tested with the short-circuit currents which would be likely to be met with in the class of circuit which they are intended to protect. It should not be expected, for instance, that a fuse on a distribution board in a house installation should be tested on a dead short circuit across station busbars.

We have restricted this paper to a consideration of fuses up to 50 amperes for house service, and in this class of installation the maximum drop in volts with the full-load current is usually limited to 2 per cent. With the fuse rated to blow with twice the full-load current this maximum drop would be doubled, so that as an average value with the normal fusing current of the fuse flowing in the circuit a drop of 3 per cent. may be taken; this value is also supported by experimental evidence. As already pointed out, this arrangement neglecting the resistance of the fuse allows of a short-circuit current $= 33 \times$ N.F.C. of the fuse.

Whether a fuse on short circuit blows before the current has time to reach the value limited by the resistance of the circuit depends upon the nature of the fuse, the amount of the short-circuit current relative to the normal fusing current and upon the inductance of the circuit.

The German regulations as to short-circuit tests are as follows:—

"The output capacity of the source of current and the resistance of the leads are to be so arranged that at the time the fuse blows the total fall of pressure in them shall not exceed 1 per cent. These conditions will be regarded as being fulfilled if in the place of the fuse an adjustable resistance is placed arranged to carry a current of twenty times the normal carrying capacity of the fuse (this current must not, however, be less than 400 amperes), and at the same time the pressure across the terminals of this resistance must not be less than the normal pressure of the circuit for which the fuse is intended, the drop in the rest of the circuit being not more than 10 per cent. of this. When matters have been arranged to comply with the foregoing conditions the switch is to be opened, the resistance removed, and the fuse replaced. On closing the switch the fuse must melt without maintaining an arc and without explosive violence."

We have found that when the short-circuit current was limited to thirty or forty times the normal fusing current for a 20-ampere fuse, the magnitude of the short-circuit current was independent of the capacity of the generators employed within the following limits:—

(1) A 50-k.w. machine.
(2) Four 100-k.w. generators with a 450 ampere-hour battery in parallel.

It would seem, therefore, that if the current rush on short circuit is limited as above for testing purposes, the capacity of the generator need only be such that it will not be seriously overloaded by the short-circuit current in question. Since the duration of the short-circuit current is so small, being of the order of a few hundredths of a second, the voltage of the machine is maintained. In our experiments two or three 100-k.w. machines were employed in parallel with the battery mentioned above.

Measurements of the order of magnitude of the short-circuit currents likely to be obtained on networks and in stations require to be made for pressures up to 700 volts.

Note on the End Caps of Enclosed Cut-outs.

In enclosed cut-outs in which the fuse wire or strip is carried through a hole or slot in the end cap or ferrule and then secured by solder or in a terminal of some sort, it is necessary to protect these holes from damage from the arc, particularly if they are used as gauging devices to limit the wire or strip employed to a predetermined size.

If the distance between the end caps is such that an arc can be set up between them, the hole or slot will either be considerably enlarged or damaged by fusion, or the wire or strip ends will become fused to the caps.

This can be prevented by a device due to one of us in which the fuse wire or strip before entering the hole or slot in the end cap or fuse contact makes contact with a washer or other easily renewable metal piece which is in electrical contact with the end caps or fuse contacts, and is therefore at the same electrical potential as they are. The damage will then be confined to the removable metal piece.

It would appear advisable to do without free holes or openings in the end caps as far as this is possible, as they not only allow of the emission of flame on short circuit, but seem to favour the persistence of the arc.

In conclusion, our thanks are due to the Principal and Committee of the School of Technology, Manchester, in the electrical laboratories of which institution the tests were made, for generous facilities for carrying out the very large number of experiments necessary, and to Messrs. E. L. Rhead, C. C. Metcalfe, W. White, J. Davies, B. Hoyle, A. K. Bentley, A. Taylor, J. Gibbs, C. Browne, and E. B. Schattner for material supplied.

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Discussion in London.

Mr. Andrews.

Mr. Leonard Andrews: There are quite a number of points I should like to refer to, but I will deal with just one or two only. On page 47 the authors refer to the curious fact that "the minimum no-arc length seems to be larger with a short circuit of ten times the normal fusing current than with a current thirty-three times the normal fusing current." This is a peculiar feature that I think all of us who have experimented with fuses have often noticed and remarked upon. On page 48 the authors suggest one or two explanations for this, and one they refer to is that the magnetic blow-out effect due to the larger current in the leads may assist to extinguish the arc. I carried out a number of experiments at Hastings some years ago with high-tension fuses, and I came to this same conclusion, namely, that the magnetic blow-out effect has a great deal to do with it. A number of those experiments were illustrated and described in a book I published some years ago, "Electricity Control"; but there is one experiment that I have not referred to before that appears to me to particularly show there is some truth in the author's suggestion.

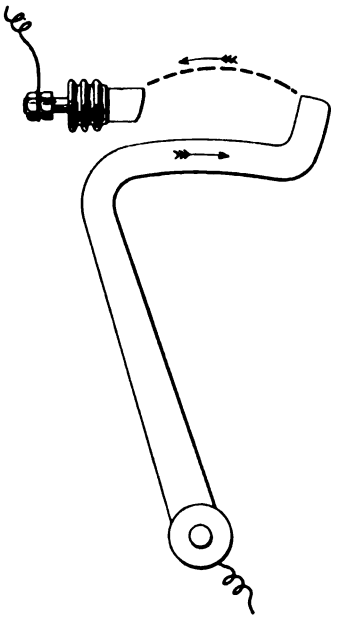


Fig. A.

I was endeavouring to utilise this magnetic blow-out effect to extinguish the arc from a high-tension switch. It was before the days when one recognised that an open-air arc is a very bad thing to use. I

constructed a trigger-switch having a moving blade of the shape shown in Fig. A. The idea I had in my mind was that as the flow of current in the moving blade would be in the opposite direction to that of the current in the arc, there would be a strong magnetic repellant effect between the two. I found that with about a 4-in. break I could reliably interrupt a circuit of about 100 amperes at 2,000 volts, but when the current was reduced to about 50 amperes then the arc was maintained, which, I think, is an effect very similar to what the authors refer to. Later on in the paper the authors refer to the effect that the shape of the angle of the cable may have upon the blowing of the fuse, and they refer to some interesting experiments. I would like to ask whether they have ever tried the effect of crossing the connections to the contacts, as shown in Fig. B. Mr. Andrews.

Under such conditions the repelling effect is very strong. I tried the experiment of short-circuiting a copper fuse wire, having a normal fusing current of 200 amperes, supported on terminals 6 in. apart, across the terminals of a 2,000 Mordey alternator. The current, which

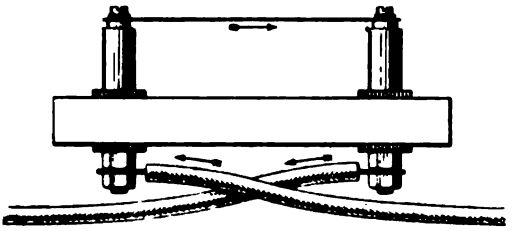


FIG. B.

probably exceeded 1,000 amperes, was effectively broken time after time by the magnetic repulsion of the current in the leads. Whereas, if the wires had been brought in straight in the ordinary way, what the authors call the minimum no-arc length would have been at least four times that length. I suggest this idea might be usefully employed in connection with house service fuses. I notice the authors say on page 48 that with enclosed fuses it was found that the results of short circuits were much more severe with 33 times the normal fusing current than with ten times the normal fusing current, that is to say, contrary to the results they got with open fuses. That has not been my experience with high-tension fuses, and it would be interesting to hear what other engineers' experiences have been. For instance, I have frequently had cases of a comparatively light fuse failing to interrupt a circuit when there has been a short circuit of perhaps twice the normal fusing current, whereas with a heavy short circuit of, say, 10 or 20 times the normal fusing current, the fuse has operated perfectly. I was discussing the same matter with an engineer in America a few years ago, who had done a lot of experimenting with fuses on circuits of 20,000 volts and over, and he told me his experience

Mr. Andrews. had been the same—that in cases where a short circuit was caused by, say, a wire going to earth, a direct short circuit, that is to say, the fuse would blow perfectly, whereas if the fuse was blown by a slight overload current then it very often blew all to pieces and failed to interrupt the arc—that is to say, the effect is very much the same as the authors have noticed with open-type fuses.

Mr. Russell. Mr. A. RUSSELL: At the beginning of their paper the authors mention several of the factors which have to be considered when judging the relative merits of different metals for fuses, but I think that they have made one or two omissions. It is well known, for instance, that the metal in the interior of an aluminium fuse is melted before the fuse ruptures. The latent heat of melted aluminium is about 77, and the specific heat is about 0·3. Remembering that the melting-point of aluminium is 657, it will be seen that about 30 per cent. of the heat in the fuse at the moment of rupture is due to the latent heat of fusion, and this cannot be neglected when making relative comparisons between fuses of different metals. Similarly the latent heats of vaporisation (if known) ought also to be given. I suppose that the numbers given in Table I. as the relative masses of the various metal fuses were got experimentally, the same length of fuse being used in all cases. It is probable, however, that the most suitable length of fuse varies with the metal of which it is made. The photographs of fuses blowing are very interesting. I was particularly struck with the photograph Fig. 3A, where the globules of molten metal are seen being projected with great velocity. I consider that in many cases when a fuse blows on a dead short circuit it literally explodes in the same way as a tube does when the pressure inside gets too high. I cannot think of any other reason why the globules of molten metal are sometimes projected to such distances. The axis of a fuse is always at a higher temperature than its circumference which is in contact with the air. This is partly due to the fact that the outside, as the authors state, oxidises and the oxidised metal is a worse conductor than the pure metal in the interior, and thus the interior heats up more rapidly. Even, however, if the conductivity of the fuse were uniform there would be a difference of temperature between the axis and circumference of the fuse owing to the radiation of heat from the surface. This difference of temperature varies as the square of the current density and the electric resistivity, and inversely as the thermal conductivity. With a trolley wire at ordinary current densities it would only be of the order of the thousandth part of a degree centigrade, but in fuses with enormous current densities it can easily be high. It may be objected that this explanation neglects the Kelvin effect—namely, that when the current is altering with great rapidity it is practically confined to a thin skin on the surface of the fuse. The authors' oscillograms, however, show the rate at which the current alters, and it is not difficult to show that at this rate the Kelvin effect is negligibly small. The metal in the interior of the fuse, therefore, volatilises first, often causing an explosion like a pistol shot, and

sometimes scattering molten globules to distances of five or six yards. The authors call attention to the fact that the fuses in Fig. 3 are out of the vertical. They have probably expanded owing to their high temperature, and the electro-magnetic forces pulling them outwards so as to make the circuit bigger are very appreciable owing to the large current flowing. I was puzzled for some time to see why a longitudinal field should have such a large effect in accelerating the rupture of a fuse. I think this is due to the fact that the fuse is not straight at the instant of melting, and so this field produces a powerful torque which helps to rupture the fuse. I wish the authors had given us a fuller explanation of the curious double peak they have discovered in the potential difference wave between the terminals of a copper fuse during rupture. There is obviously some physical discontinuity in the phenomenon which causes this, but it is not obvious whether it is merely mechanical or whether it is a change from the spark to the arc type of discharge and back again. It would be of interest if the authors discussed this a little more fully. The statement that "the temperature rise of the jacket is a function of the diameter of the cartridge employed" is not quite rigorous. The difficulty heat has in getting through a tube is a function of the ratio of the outside to the inside diameter of the tube, and hence the resistance to the passage of heat can vary, although the outside diameter remain constant. A careless reader might infer from Fig. 26 that a Trent sand filling was the best. This is not necessarily the case, the heat generated has to be got rid of somehow, and if it cannot be conducted through the cartridge, it will be conducted to the ends which may heat excessively. In the last column of Table X. the ratio A/B is called the "rating of the fuse," but a little lower down the "rating of the fuse" and the normal fusing current are taken to be the same. It seems to me that it would be better to call the ratio of A to B the normal factor of safety of the wiring. We might call half of this the emergency factor of safety. Multiplying the emergency factor of safety by the I.E.E. permissible load in amperes we would get the normal fusing current which would also equal half the current required to raise the wires to the I.E.E. maximum safe temperature of 54·4° C. Mr. Russell.

Mr. W. H. PATCHELL: If I remember right, Mr. Mordey's was one of the first enclosed tube fuses invented. The authors appear to have found out that zinc and aluminium are both bad for fuses because they oxidise. Years ago we had to give up lead for that reason, because when it was put into damp cellars a skin formed on it just like a caddis-worm's case, with quite hard scale on the outside, so that there was *bonâ-fide* molten metal inside which would carry the current long after the fuse should have gone. I had to go into the question of fuses some years ago, more particularly for street work. Some people have tried to fuse the ends of their feeders, but I never like to do that because the current to be handled is too great. For house fuses we never had any trouble. The only consideration is to put in a fuse that will not melt, but will protect the meter. If it is Mr. Patchell.

Mr. Patchell.

the consumer's fuse melts then one is happy; he does not send in the middle of the night to renew his fuse. But in street work, as the district got bigger and bigger, it became important if we had an accident on the mains, and for the sake of all the other people who happened to be working near the mains, to limit the extent of the damage. We then tried to find fuses which we could put in at certain places in the net-work where the sub-areas joined, where we only had to carry what one may call the balancing current between those different areas. The main consideration then was a fuse which would not cause a gas explosion in the street box, because in addition to other people working in the streets we had the gas companies. We tried various forms of "no-arc" fuse, enclosed fuses, etc. We started with those first mentioned by the authors, which we enclosed in cylinders of red vulcanite. Those were not very satisfactory on account of damp. Then we tried metal casings, and we finally got to a form made of steam-barrel, in which we found we were working alongside, if not actually infringing, Peard's patent, and I think they were handed over to his licensee, who made them for us eventually. We sent round to all the different makers of what they called "silent" fuses and gasproof fuses for samples of their manufacture, which we tested. One day I remember we were having a Board meeting; I was in the Board-room, which overlooked a sub-station, with the directors when there was a tremendous explosion. One of the directors said to me, "Is that a boiler?" I felt quite happy on that score, because I was able to say "No, we have no boilers here; it is only a sub-station." I telephoned down, and I found it was due to the fact that my superintendent was testing a "silent" fuse! We also tried various methods of filling the tubes. We did not try Trent sand or Calais sand. The authors might tell us what is the difference between those two sands. They only mention the difference in size, but they might tell us whether one is a silica sand and the other has more alumina in it, or what is the difference. We tried marble dust, and then, because we could get it more readily, plaster of Paris, and I did not find any better material than that. It did not seem to make much difference whether it was poured in wet or dry, it would get solid. The authors have referred to the question of the power behind the fuse. I have heard experimenters say that it makes no difference. That is not my opinion based on experience. We have tried fuses on 100 volts, which acted quite well, and the arc did not carry over. We have tried those same fuses on 200 volts and 400 volts, and they have been an absolute failure. Finally, I would not pass a fuse at all for 200 volts if it would not act when the switch was closed dead on without any resistance at all with a 400-volt battery, which would give 1,000 amperes for four hours on discharge. We thought if the fuse stood that we could safely trust it for 200 volts. I should like to see the theory backed up a little more by those who are of the opinion that the power behind the fuse does not affect the fuse. One difficulty that we have in connection with fuses is that the blocks are made to

take various sized fuses. The cooling effect then is very serious and quite upsets the fusing points. A block should be made to carry only its proper fuse. As to the question of the rating of the fuse, we have all sorts of rating. Sometimes a foreman is told to put in 100-ampere fuses, and he puts in fuses which would blow at 100. Again, another foreman is told to put in 100-ampere fuses, and he puts in fuses which will carry 100 and will blow at 200. I wish we could get more definite ruling as to how a fuse should be rated. I think it is an open secret that part of Professor Schwartz's experiments have been carried out at the instigation of the British Standards Committee who have this matter in hand, and it is a pleasure to be able to get a little ahead of the Standards Committee themselves, and thank Professor Schwartz for giving us an opportunity of discussing the matter here in public. For heavy currents one has practically given up fuses entirely and taken to automatic switches, which are the only practical means of handling heavy currents, not because with fuses the circuit cannot be opened, but on account of the time taken and the difficulty which is caused in replacing the fuses. It is so much easier to put the automatic in again, and also if one happens to put it in again on a "short" it will not hold in, but will fly out. I have often seen a fuse for low tension with a shunt fuse in parallel which was supposed to go last. Personally I have never tried it. For high-tension work when we started with 10,000 volts we started with two fuses in parallel. The main fuse in a tube about 1 in. diameter, with the terminals about 12 in. apart, and the tube open at each end. Alongside it there was a small tube about ¼ in. diameter, and a small fuse threaded in it. The big fuse went first, and the little fuse was supposed to go last, but we gave those up due to the surge caused by the arc when the fuse acted. We then tried oil fuses. For 1,000 volts continuous current I had for several years been using the Ferranti fuse, but it was impossible to calibrate it due to the cooling effect of the oil. We used an elaborate type of oil fuse which I illustrated in my paper on the Bow Works. Those who are interested in oil fuses can turn to that paper (Vol. 36, p. 96). The fuse, although it was called an oil fuse, was just above the surface of the oil as regards the actual fusible portion, in a little inverted cup. As soon as the fuse acted, it was drawn down into the oil before there was any time for a surge to take place. It had the advantage that the fusible portion was in air, and that it could be calibrated without the interference of the cooling effect caused by the oil. We also tried "sparklet" fuses, but for heavy currents I did not fancy them at all. We did not get good results with them. I should like to make a suggestion with regard to Table X. In that table the authors have given us the diameter of the wire in inches: we are so used to thinking of the current-carrying capacity of a wire by its area, that if they would not mind giving us the areas of wires, it would help us in our comparisons. We should then get right off what the current would be which we expect the wire to carry. Therefore I ask them if they would not mind giving us another column showing the areas.

Mr. Patchell.

Mr. Paterson.

Mr. C. C. PATERSON: In 1892 Mr. Russell and myself published in the *Journal* of this Institution * the results of some tests which we made with the object of endeavouring to find a basis for the rating of switches, but we proceeded on a method which was a little different from that of the authors. We measured the actual lengths of the sparks which resulted when circuits of different currents and voltages were broken—it was a question of damaged contacts and the distance which must be allowed before damage to contacts ensued—and we found that when the switch was sharply brought beyond the critical length of spark which corresponded to a given current, practically no damage ensued to the contacts. If, on the other hand, the switch was stopped before this length of spark was passed, there resulted a flare which might be said to cause damage to the contacts. We did not, of course, work with such large currents as the authors have used in their short-circuit tests, but where they used the smaller currents we are able to compare the results; and, on the whole, the distance, which we called the safe sparking distance, comes out something over 50 per cent. greater than they give as their minimum no-arc length. That is quite capable of explanation, because in a fuse it does not matter if the contacts do get a little bit damaged, whereas in a switch, on account of continual making and breaking, one wants to avoid all damage. I should like to ask the authors whether it is really an easy method to gauge this no-arc distance, and whether the judging of the amount of damage to the contacts does not allow a very large margin of uncertainty. I ask this chiefly because of the curious results which they get in Table III., which have already been commented on. Would the authors suggest on the basis of this table that for severer short circuits the shorter length of distance should be allowed? The fact of these curious discrepancies occurring in this table, due to whatever cause, seems to show that perhaps some other basis ought to be adopted for gauging the several distances at which the terminals are to be apart. I venture to suggest that for the scope of work which they have covered in the paper (which only deals with comparatively small short circuits for house work) to take the proportion of the spark distance which is caused by breaking various currents at different pressures, will possibly give more consistent results than are obtained by attempting to judge the distances at which the contacts do not become damaged. I only throw this out as a suggestion, because I have not worked in the way the authors have in their particular method, but one would be rather interested to hear their views on the point.

Mr. Mordey.

Mr. W. M. MORDEY: It is true, as Mr. Patchell said, that I have had something to do with the introduction of enclosed fuses. Over eighteen years ago I was working at the subject, and I have almost forgotten the experiments that were then made; but I think the preference the authors express for copper is one that has been held for many years.

* *Journal, Institution of Electrical Engineers*, 1902, Part 157, vol. 31, "Sparking in Switches," by Alex. Russell, M.A., and Clifford Paterson. (Original communication.)

Mr. Mordey.

It has long been recognised that copper or silver are the best metals for fuses. What was wanted was a metal that gave a lean vapour—as little matter in it as possible. But for very small currents it was not practicable to get copper wire thin enough, and for that reason metals or alloys of higher specific resistance were used. The effect that Mr. Patchell has very aptly described as the formation of caddis-worms, and which the authors have referred to as the formation of tubes, some examples of which are given in the paper, is an effect I came across in experimenting with the filling for enclosed fuses. I tried many substances. I avoided all forms of sand, glass-powder, and everything that was at all likely to form, when fused, a conducting liquid. I tried marble dust, and often used it, but finally I settled down on a very unscientific material, but one that I found to be the best—flue dust, the dust scraped out of boiler flues. It is a highly infusible material, and I found it answered well—better than anything else. When copper wires were fused in an envelope of flue dust not too tightly rammed, one could hardly ever find, on emptying the flue dust out, any trace of the copper; it had been vaporised and apparently condensed all through the mass of the flue dust. Reference has also been made to the more readily oxidisable metals having oxide tubes formed which, the authors say, conduct as Nernst lamps. I certainly thought in these cases it was the molten metal inside that conducted. One can take a straight wire of aluminium, for example, and make it form quite a long U when heated carefully with such a current that it will not blow. The molten metal, protected by a skin of oxide, will draw out by its own weight. With regard to shunted fuses, one does not like to get up and say "I did it," but I may say that in the patent I took out a good many years ago for enclosed fuses, I described a shunted fuse, and I often used them, putting a little resistance in with the fine fuse so as to make sure that it went appreciably later than the big one. They seemed to work all right. With regard to the question of rating, I was hoping to hear something about the effect of time. My experience is that it is very difficult to rate fuses. They may be rated, and they will keep their rating fairly well for a time, but the life of a fuse is not a happy one—often it is nearly melted, and it goes through various changes; it is oxidised, expanded, contracted, and so on. Under such conditions all metals change, and I think that will always cause difficulties in getting fuses to stand up to their rating for any length of time. One point which may be of some interest now: I sometimes found that copper wires, when examined under a magnifying glass, showed after a long period of use a multitude of little transverse cracks, cracks that sometimes seemed to go right down into the metal. I was reminded at the time of the fact that Edison, when he was working on platinum lamps in the very early days, had to give them up because he found that the life was so short, and he attributed this to the gradual growth of minute transverse cracks in the metal itself. With regard to the arrangement of the conductors to help the blow-out of the fuse, I suppose we have all invented that arrangement at one time or another.

Mr. Mordey. There is quite a long list of patents for that, so that the field set up would help to elongate and break the arc. It is a practical arrangement which, I think, is quite worth while putting into a simple form for house fuses, especially now that we have rather higher voltages.

Mr. Sayers. Mr. H. M. SAYERS: I have made pretty extensive use of copper wire for street main fuses on secondary networks. Where it was desirable to isolate transformers, if anything happened to the transformer or to a particular section of main, I found copper the most useful and trustworthy material, always provided that it was changed sufficiently often. "Sufficiently often" I found meant twice a year, not at six month intervals, but about the end of August and about the end of January, so that the time of heavy load was fairly divided. Under those conditions copper could be relied upon to blow at a very definite rate.

A word of warning is desirable against the use of tinned copper wire. Such wire is irregular in its fusing current, consecutive lengths off the same coil giving wide variations. The effect is most marked with small wires, but is serious up to at least No. 14 S.W.G., and is no doubt due to different depths of penetration by the tin.

Mr. Wordingham. Mr. C. H. WORDINGHAM: There are a few remarks I should like to make, more especially with regard to the work of the Standards Committee, because this subject has been taken up by the Sub-Committee of which I have the honour to be chairman. The thing which struck us most when we began to discuss the question of fuses was the extreme difficulty of the various problems connected with anything in the nature of standardisation. To begin with, it was difficult to classify fuses. We thought at first of having open fuses, protected fuses, and enclosed fuses, but we found that an open fuse became a protected fuse if put into a box; and we have not settled how to classify them yet. With regard to the question of rating and so forth, it is wonderful how little is known at the present time with regard to fuses, in spite of the great amount of work that has been done upon them; and we arrived at the conclusion that a great deal of experimental work must be carried out before we could attempt to standardise these very important articles. We have laid down a common basis for the tests, and taken steps to secure that the experiments shall be carried out on uniform lines; so that we hope when we do standardise fuses our suggested regulations will be founded on experimental data of considerable value. I would like to remark on a few more points that have been raised this evening. I cannot help thinking that those of us who think that the amount of power behind the fuse has something to do with the matter, and those who think it has little to do with the matter are really talking about two different things. It will be noticed that the authors' experiments all relate to a wire between two contacts which are fixed at what they call the "no-arc" distance. I agree that experiments on those lines are necessary as the foundation of any standard conditions for fuses, but the container in which these fuses are carried has also a very great deal to do with their action in practice. A

good many years ago now, when 220-volt lamps were first introduced, I made a number of experiments on the then existing 100-volt house fittings (I am speaking of quite small fuses) to see how they would stand at the higher pressure, and I found that the amount of power behind the short circuit made an enormous difference. At that time I introduced a system of registering fittings. I thought that if I tested the fuse with 30, 40, or 50 times the normal fusing current I was sufficiently well imitating a short circuit, and I registered a number of fuses on those lines. Later on I thought it well to repeat the experiments, and I then tried the same fuses by short-circuiting them dead across a large battery, and in a great many cases I found those fuses which had passed the first test failed altogether on the second. I have no doubt that if the fuse wires had been supported between two open terminals as in the authors' experiments there would have been no difference between the two tests, because I think their oscillograph tests show conclusively that after a certain amount of power an excess will make no difference; but the explosive action, as it were, of the fuse by the sudden development of the heat does vary very greatly in my experience with the amount of power behind. With regard to fillings, I recently made some experiments to ascertain the amount of caking that might be expected in damp situations. I had a large number of fuses made up with different materials, such as fine and coarse emery, fine and coarse steatite, different sands, chalk, limestone, and a great many other substances. I sent them to sea for three months; and on opening them I found that in no case was there any caking, so that I do not think one need fear caking so much as one thought. Mr. Wordingham.

Mr. J. J. FASOLA: With the data before us there should not be any difficulty in selecting suitable materials and no-arc lengths for low pressures, and I am sure we should be very grateful if the authors could give us similar information with regard to high-tension fuses. For fuses of the order of 5,000 to 10,000 volts, for instance, the conditions seem to be quite different, and I think there is a general tendency to resort to the aid of oil. I have seen some very large porcelain cartridge-type oil fuses on the Continent, some of them quite a foot in diameter. Notwithstanding their large size they were not a complete success, and of course they are very difficult to handle. If the fuse were entirely in air and arranged so that the lower contact would be drawn under oil at the moment of disruption, the fusing current could be predetermined fairly accurately, but the metal vapour very often causes sparking across to exposed metal in the neighbourhood. If, on the other hand, the fuse is completely immersed, it is conceivable that it would be necessary for a film of oil vapour to form round the silver wire before it could blow, and as the conditions of vapour formation, circulation of the oil, and thermal conductivity are never the same twice running, it is impossible to rely on the fuse to blow at predetermined overloads. Mr. Fasola.

When the fuse was partially immersed matters were still worse,

Mr. Fasola. because the fusing-point depended upon the level of the oil. The best solution of the problem I am acquainted with is the cut-out mentioned by Mr. Patchell,* which I think possesses rather important points of interest. The fuse wire is contained in a strong insulated inverted metal cap closed at the top and opening into the oil at the bottom, and thus it blows entirely in air, and can be calibrated with accuracy. At the same time the explosive forces act vertically downwards instead of laterally on the glass, thus allowing a tube of moderate dimensions to be used, and all the hot gases are blown down into the oil and do not come into contact with metal parts outside the fuse. A spring attached to the lower terminal draws the latter under oil directly the fuse goes, so that the oil separating the terminals, aided perhaps by the high pressure in the fuse chamber, exclude any possibility of prolonged arcing, notwithstanding the high pressure across the terminals.

Experiments have been carried out whereby two generator units of 1,000 k.w. and 10,000 volts were short-circuited upon each other through Lahmeyer fuses, and all that could be observed was a slight puff of oil vapour about a couple of inches high, and it was then experimentally determined by placing a conductor of opposite polarity about 2 in. from the top terminal that no metal vapours were expelled from the fuse. If there had been an arc would certainly have been set up across the gap, but although the experiment was repeatedly made this did not happen.

Data regarding well-designed high-tension fuses of moderate dimensions would be very welcome, owing to the considerable expense of installing overload circuit breakers where interruptions are of infrequent occurrence.

Mr. Wakefield. Mr. JOHN H. M. WAKEFIELD (*communicated*): I recognise that the paper does not deal with fuses of so low a nominal fusing current as 3 amperes, but as a considerable number of these are used by the Post Office for protecting telegraph and telephone wires against lighting and power circuits, it may not be considered out of place to put on record that all such fuses outside a building are made of soft drawn platinum wire, 5 mils in diameter, connected to copper caps and enclosed in a glass tube 0·3 in. diameter and 2 in. long. Platinoid wire was used in the first instance, but weather effects soon showed that disconnections in the fuses were very frequent, especially after a frost. The effect of contraction and expansion, as mentioned by Mr. Mordey, no doubt applies to a case of this kind. Platinum wire was therefore substituted, and up to the present has been found to meet requirements satisfactorily.

Mr. Schattner. Mr. E. B. SCHATTNER (*communicated*): I should like to make some comments on various matters mentioned in the paper. In the first place, it has been my experience, gained under the severest working and short-circuit conditions, that fibre is the only material which will

* An illustration of this appliance is given in Mr. Patchell's paper on the Charing Cross Company's City of London Works, in vol. 36, p. 96 of the *Journal*.

Mr. Schattner.

answer satisfactorily as a casing for enclosed fuses. Neither glass nor porcelain have the necessary elasticity and strength to withstand the shock of a bad short circuit. An insulated metal tube would, in my opinion, be a very dangerous thing to employ, and liable to cause grave accidents.

Copper and silver are undoubtedly excellent fuse metals, and excellent results have been obtained with zinc. Aluminium, however, is dangerous, as it is liable to flux with almost every filling and produce a Nernst effect, especially on limited load short circuits such as are mostly obtained.

The fluxing of the conductor and filling resulting in the entire filling becoming a conductor of the second class directly after a short

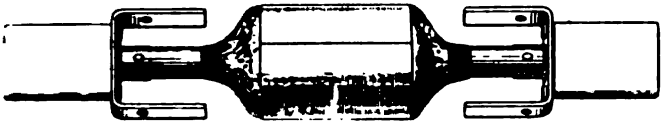


FIG. C.

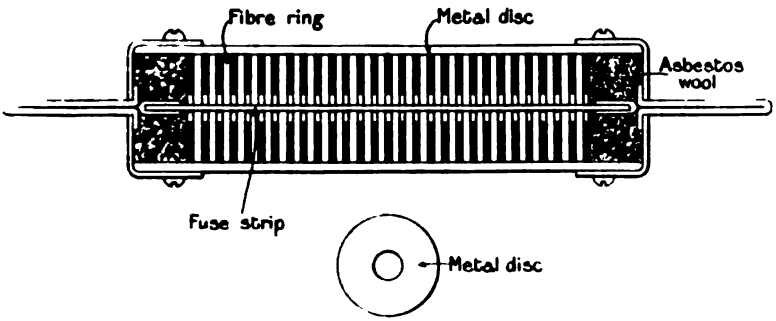


FIG. D.

circuit, is a matter which has to be carefully avoided, and for this reason most, if not every, kind of sand should be avoided as a filling. I have watched sand-filled fuses re-establish a short circuit after about 60 seconds.

Some mention is made of shunted fuses and their possibilities. The proper effect of the shunt, however, is only obtained on circuits of little power, and when such fuses are tried on heavy power circuits, they act very badly. The main and shunt fuses seem to fuse at the same instant when sufficient power is behind.

I have come to the conclusion that the essential requirement in a good enclosed fuse is the immediate *cooling* of the arc and vapours. This was amply proved by experiments made by me at Niagara Falls and Schenectady. The types of fuse shown in Figs. C and D work on this principle and are very efficient. The "Koolark" fuse also works on the same principle.

Dr. Garrard.

Dr. C. C. GARRARD (*communicated*) : The definition of normal fusing current as given by the method of measurement enunciated on page 74 of the paper is no doubt perfectly correct. The time-current curve tends toward an asymptote, and the point where this asymptote cuts the current axis is the normal fusing current. No current below this value, no matter how long it be kept flowing, should blow the fuse. I was under the impression that the authors in their previous paper on "Low Tension Thermal Cut-outs"* had adopted a different definition of "normal fusing current," and I should be glad if they would say whether the normal fusing current in all their papers dealing with this subject has always been defined in exactly the same manner.

"Non-arcing" Metals.—Some years ago we heard a great deal of the discovery of the "non-arcing" metals. I have never been very clear as to the distinguishing features of this "non-arcing" property. I understand metals of the cadmium (or zinc) group entered into the composition of these metals. The oscillograms given in Fig. 8 seem to show that these particular "non-arcing" metals are more than any of the others. I am inclined to doubt the existence of any special "non-arcing" property.

Definition of Short Circuit.—The authors state that under the conditions of their tests it did not make any difference, at any rate within the limits experimented upon, what power was behind the tests. In my own experience of fuse testing, the "amount of power" behind the tests has always been the most important factor determining the severity of the tests. My own tests, however, have generally been with fuses of large sizes (several hundreds of amperes), and have taken place close up to the terminals of the source of supply of current. The tests so obtained are very much more severe than the tests described in the paper. The most severe conditions seem to be close up to the terminals of a large battery. By using a large 500-volt battery, and shorting the same through short lengths of thick cable, and the fuse, results are obtained which are extremely severe, and necessitate great care being taken to prevent damage to the experimenter or surrounding property.

Time Element of Fuses.—I am mostly interested in this branch of the question. I do not agree with the authors' definition of the time element of a fuse as given on page 77. The object of this definition, I take it, is to arrive at some time element which could, for example, be marked on the fuse. Now the ordinary user, seeing this time marked on the fuse, will think that this is the time taken to blow the fuse. He will not realise that it is the time corresponding to some particular current, and that if the current be a little different from the proper current, say 45 or 55 per cent. overload, the time element would be altogether different. I have had exactly the same experience with inverse time element relays. Of course, the time element of a fuse is also inversely proportional to the extent of the overload as in the case of such relays. It was at first endeavoured to mark

* *Journal, Institution of Electrical Engineers*, vol. 35, p. 364, 1905.

these relays with certain specified numbers of seconds. It was found extremely difficult to induce even engineers to understand these markings. The user saw, for example, the relay marked 5 seconds, and, assuming the apparatus to be a kind of a clock, proceeded to test it with a stop-watch. Generally speaking, no particular regard was paid to the current flowing through the relay, and if the time came out, say 4 seconds or 6 seconds, the relay was said to be out of order. In view of this experience, the conclusion I have come to is that the inverse time element of any circuit-breaking apparatus should only be defined in terms of a curve. If the full curve cannot be given, it is better not to mark the time element at all. To illustrate this, we will take the curves given in Fig. 23 of the paper. These are two fuses of the same normal fusing current. Defining the time element in accordance with the authors' definition, that of the free fuse is about 4 seconds; that of the enclosed fuse about 1 second. I think now it would be an assumption legitimately made by 99 persons out of 100, that if these two fuses were placed in series with each other, and the same overload current passed through them, the 1-second time element fuse should blow before the 4-second time element fuse. This, however, does not follow. If the overload is but small, just above the normal fusing current (say, 15 per cent.), then the 4-second time element fuse blows before the 1-second time element fuse. If, on the other hand, the overload be very large, as, for example, several hundred per cent. above full load, it will be a matter of chance which one blows first, as it will be seen that if the curves are prolonged, the time element disappears altogether in both cases. I think it will be agreed, therefore, that the proposed time element marking of these fuses would be distinctly misleading, and that the only clear way in which an indication of the results to be expected can be given is to give the complete curves. I am strongly of opinion that it would be disadvantageous to adopt the authors' suggestion of a definition of time element (page 77). Dr. Garrard.

The matter of time elements of fuses is also of great importance in connection with another subject. I refer to the fuse-shunted trip coils which are used very greatly at the present day to impart a time element to automatic alternating-current circuit breakers. Of course, an ordinary trip coil operates practically instantaneously, and the idea is, by shunting the current through the fuse, that the time taken by the fuse to blow will impart the necessary time element to the apparatus. I have dealt with this matter to some extent in a paper now before this Institution, but I would like to say that the results given by the authors confirm the conclusions I had arrived at. The main object of a time element circuit breaker is to attain the possibility of having two or more circuit breakers in series, so arranged, that with a definite overload through them they will open in a predetermined order. In my paper referred to, I am showing that it is not possible to attain this end by simply altering the size of the fuse wire. Professor Schwartz and Mr. James's paper also shows that it is quite impossible to arrive at this end by

Dr. Garrard.

altering the materials of the fuses or the surroundings of the same. For example, consider Fig. 21, which shows the variation of time element with fuses of the same diameter wire but in different surroundings. From a casual examination it would appear that the time elements are nicely graded. This is so for small overloads. Under conditions of short circuit, however—that is, with currents at least three or four times the normal fusing current—it will be seen that the time elements all become approximately the same—that is, they all become practically zero. Under conditions of short circuit, therefore, it is impossible to arrange switches in series one with another controlled by fuse-shunted trip coils such that a discriminating action between the switches will be attained. It will be noted, too, that in the attempt to grade the time elements (Fig. 21), the normal fusing current has been varied 75 per cent., so that the current settings of the switches will be greatly affected. If, on the other hand, the normal fusing current be kept constant by using wires of various thicknesses, then Fig. 23 shows the liability of the time curves to cross and the time elements to vary in their gradation. The general conclusion may be drawn, therefore, that it is not possible to time-grade fuses of constant normal fusing current so that they will blow in a predetermined order under all conditions. The order of their blowing will depend on the degree of the overload. Therefore, the attempt to time-grade circuit breakers by shunting their trip coils with fuses is likewise bound to be unsatisfactory. One is forced to the conclusion that some kind of an electro-mechanical controlling device must be used.

Dr. Morris.

Dr. D. K. MORRIS (*communicated*) : A valuable quality of fuses as compared with magnetic circuit breakers is that the time element of which Professor Schwartz gives interesting data is based on heating, and is therefore just that which is proper for the protection of circuits or windings of motors from over-heating. But as a method of breaking the circuit in a satisfactory manner, it must be admitted that there is no comparison between a fuse and a circuit breaker, and that the latter with carbon break is a much better way, and with large currents a less expensive way of breaking a circuit than is a fuse. What appears to be required in order to combine the advantages of the fuse and the circuit breaker is to construct a simple type of switch which will hold in only in virtue of the fact that a portion of the circuit remains nearly cold, so that a very moderate heating and not extreme over-heating and fusing shall open the circuit. Such a circuit breaker can be made by causing the current to pass through two parallel strips of hard metal secured to the arm of the circuit breaker and carrying steel catch-pieces, which are sprung open (when the circuit is closed) over an adjustable fixed catch placed between the contacts. If the current then increases unduly, the strips, which can not expand endways, are constrained to move out laterally and so release the circuit breaker. I have found that this type of circuit breaker works extremely well in practice, and it certainly combines the advantages above referred to.

The PRESIDENT: I call upon you now to accord a hearty vote of thanks to the authors for their paper, and I am sure they will add to its interest by replying to it as fully as possible in a written communication. The President.

The vote of thanks was carried by acclamation.

The meeting adjourned at 9.33 p.m.

DISCUSSION AT MANCHESTER, MARCH 3, 1908.

Mr. W. CRAMP: I realise fully the amount of work involved in obtaining such curves as those in Fig. 4 of the paper, for which the authors made more than eight hundred experiments. Mr. Cramp.

Many points in the paper have their special interest; but as regards Professor Schwartz's hope that the work in the paper is in such a form as to be useful to designers, I find that it is very difficult to deduce immediately from the results the best form for a fuse intended for any special purpose. I think this difficulty might be largely removed by the addition of a summary of results. I should like to suggest the possibility of attacking the whole subject from a rather more theoretical point of view, especially certain sections of the present paper. We know that Preece's original fuse formula was derived from the following equation—

$$C^2 = K\frac{J\,T\,E}{P}D^3$$

where—

K is a constant.
D is the diameter of the wire.
C is the fusing current in amperes.
J is Joule's equivalent (gramme-calories).
T is the elevation of the temperature of the wire at fusion.
P is the specific resistance of the wire at temperature of fusion.
E is the emissivity in gramme-calories per second per degree at temperature of fusion.

Now Preece introduced inaccuracies by assuming everything constant but C and D and by writing the formula—

$$C = K' D^{\frac{3}{2}}$$

where K' is a constant and has a value of about 40 when D is in inches.

In 1892 Ayrton and Kilgour * found the values of E for platinum wires up to 0·014 diameter, and pointed out that taking E as constant would make an error of "hundreds per cent." in some cases. Indeed, their curve plotted on a diameter base shows that E varies from 0·002 to 0·005 or more for wires of diameter varying from 14 mils to 3 mils.

E. G. Brown † showed in 1900 that tin wires have emissivity values

* *Phil. Trans.*, 183 A, p. 371, 1892.
† *Transactions of the New Zealand Institute*, vol. 33, p. 364.

Mr. Cramp. almost similar to these of platinum, and not incompatible with the values well known for steam pipes. What we want, then, now is to continue this line of thought and obtain values of E and K for the following variables:—

1. Different metals exposed in air.
2. Different metals enclosed.

Both to be taken with terminals of large and small mass and of various materials.

It seems to me that the lengths chosen should be based upon results, like those of Fig. 4, which to my mind is the best set of results in the paper. Such a research would give us once and for all a good basis, scientifically accurate, upon which designers could rely with some certainty.

Turning now to some points in the paper itself, I wish to call attention first to a statement on page 44 referring to Fig. 6 B, where a photograph is shown containing lines, which the authors say were due to the hot beads of tin thrown out, and from which they conclude that these beads were luminous. The evidence does not seem to me conclusive, since a hot globule, whether luminous or not, would probably be sufficiently active to affect a sensitised plate.

Next I should like to ask for some definition of the word "arc," which occurs first on page 46. Is any distinction drawn between the vapour arc and the oscillating discharge?

On page 55 the authors say: "In practice, inductive circuits will be met with in such and such cases." But I venture to say that for the purposes of this paper the circuit is *always* inductive. Indeed, this contention is amply justified by the many excellent oscillograms, which in the very shape of their curves amply testify to the truth of my contention. I must also ask how the inductances mentioned on page 55 were measured, for some of them appear to me to be wrong in magnitude.

Again, with reference to the explosive force of a fuse mentioned occasionally in the paper, it would seem that, just as Professor J. J. Thomson has shown how this may be estimated for a disruptive discharge, so in the cases given here the rise of pressure might have been estimated, and would probably have shown itself to be of the order of 600 atmospheres.

On page 57 reference is made to three curves—(*a*) No magnetic field, (*b*) lateral magnetic field, and (*c*) longitudinal magnetic field. These terms seem to me to be misleading, inasmuch as with the particular arrangements adopted the distribution of flux would be such as not properly to be characterised by either term. In either case part of the field would be "lateral," part "longitudinal." The results, however, attained with the arrangement shown in Fig. 9 are very remarkable.

The authors have not called attention to a marked effect visible in curves A and B, Fig. 11. In virtue of the fact that in B there are more turns on the blow-out coil, the blow-out should be much more

marked than in A. The reverse, however, is the case, showing that the inductance added by the blow-out coil more than compensates for the blow-out effect—a very important fact. Mr. Cramp.

The conclusions mentioned at the bottom of page 66 with regard to Fig. 19 are evidently only true for the upper portion of the curves not shown in the diagram, that is, it is only at high overloads that enclosed fuses are quicker than open-type fuses.

Finally, I wish to call attention to a number of enclosed fuse samples which I tested for Professor Ayrton some years ago on behalf of the Admiralty. We found that by far the best enclosed fuse was Siemens & Halske's silver wire embedded in plaster of Paris, which never failed to act. On the other hand, Dorman & Smith's damper porcelain holders smashed frequently on short circuit, and on limited overload the No-arc fuses were very unsatisfactory, for they would blow and still continue to carry almost full-load current with a slightly higher resistance.

Mr. C. F. SMITH: I do not feel able to consider in detail the large number of experimental data included in this paper, as a good deal of time would be necessary in order to study them sufficiently to gather all the information embodied in the results and to form a correct estimate of their value. There are, however, one or two points connected with the general method of carrying out the tests on which a little more information from the authors seems desirable. Mr. Smith.

In the first place, the majority of the tests were carried out on a circuit with a definite resistance sufficient to produce a drop in the circuit of 3 per cent. with the normal fusing current of the fuse. It would seem at first that a rather arbitrary condition was thus adopted, and that the usefulness of the results for general conditions might be found to be considerably lessened thereby. The authors state that this drop of 3 per cent. is found to be representative of the conditions likely to be met with in house services for mains and distribution fuse-boards, and I would suggest that the information which they have collected as the ground for this assumption would be very valuable, as showing to what extent it is permissible to assume a constant drop in such cases.

The "drop" in the leads of the circuit does not, however, depend only on the resistance of the circuit when a sudden rush of current occurs. It is more particularly in connection with the other factor producing the drop (namely, the self-induction) that I wish to make a few remarks. I had the curiosity this morning to calculate roughly the value of the self-induction in an ordinary 2-wire circuit. I took as an example the case of two parallel conductors separated by a distance equal to ten times the radius of the conductor. On this basis the self-induction works out at about 0·1 millihenry per 100 yards of circuit. Assuming that the circuit upon which the fuses are to be blown is 100 yards in length, and taking the rate of fall of the current after its maximum value is reached from the oscillograms in the paper (for example, Fig. 8 B) to be 33,000 amperes per second, the voltage set

Mr. Smith. up in the leads by self-induction during the blowing of the fuses would appear to be—

$$L\frac{dc}{dt} = \frac{33{,}000 \times 0{\cdot}1}{1{,}000} = 3{\cdot}3 \text{ volts},$$

that is, the "drop" in the conductor due to self-induction would be greater than the "drop" due to resistance.

This, however, is not a fair measure of the effect of the circuit inductance, because the value of $\frac{dc}{dt}$ is taken from the authors' curves obtained with a choking coil in the circuit, of which the self-induction is given as 23 millihenries. The rate of fall of the current in a circuit without artificial inductance should be about 230 times as great as that just found; that is, we ought to get a reverse E.M.F. in the circuit on breaking having a value of $3{\cdot}3 \times 230 = 760$ volts. I do not think that anything like so large a rise would actually occur, because there is evidence from the authors' curves that the inductance of the choking coil which they employed was much less than 23 millihenries at the moment of melting of the fuse. What I wish to emphasise, however, is that an E.M.F. of self-induction of large value compared with the total voltage applied to the circuit will certainly be formed in a circuit which would be termed by the authors "non-inductive." From the figures just given, it is evident that a circuit having a true self-induction of 23 millihenries would show a very much higher rise in voltage than anything shown on the oscillograms.

Doubtless iron saturation and capacity effects in the winding of the coil have actually had a great influence at the moment of fusion, and the value given for the inductance of the coil cannot be taken as any guide as to the value of the actual inductance of the circuit.

On looking at some curves given by Oelschläger in the *Electrotechnische Zeitschrift* for 1904, I find that on a short circuit made as nearly "dead" as possible the value of the rate of change of current was practically 9×10^6 amperes per second. The conclusion I should like to draw from this is that the self-induction of the circuit is a matter of absolutely vital importance to the manner in which the fuse blows, and that when a circuit is stated to be "non-inductive" this must be clearly understood as a relative term, and that the amount of inductance in an ordinary lighting circuit is by no means negligible, when considering the effect of a short circuit. I venture to think that the authors have hardly considered this point sufficiently.

I should like also to refer to the formula Mr. Cramp has already mentioned on page 74. I had some difficulty in understanding the meaning of the calculation on that page, but I think this was probably due to a want of a clear understanding of the authors' definition of "rating." "Rating," as far as I can see, is synonymous with the normal fusing current in the paper. If so, the rating of the fuse is simply the current required to produce the maximum permissible temperature, divided by the factor of safety.

Mr. Smith. One last point in connection with the capacity of the generators. The reason why the effects obtained by the authors appear to be independent of the capacity of the generators is the relatively large drop in the circuit compared with the drop due to armature resistance of the generators' armature. It is not really the capacity of the generator which determines the extent to which its voltage is maintained during a momentary short circuit, but its inertia, mechanical and electrical. Except for the drop due to the armature resistance, I should prefer to say that the effect of size of generator depends really on mechanical and electrical inertia (that is, self-induction), although, of course, inertia and output capacity will usually vary together. This point is not very clearly expressed by the author.

Mr. Watson. Mr. S. J. WATSON: I am rather sorry the authors have not given us more information on the metal aluminium. Most of the experiments deal with copper and with tin and zinc, but aluminium is hardly spoken of at all. Now that is one of the metals which, personally, I have found a great deal of use for, and, I may say, particularly in connection with feeder and distribution section boxes placed above ground in different parts of the town. The metal is, I think, excellent for that purpose. These fuses are about 200-ampere normal carrying capacity, and we do occasionally have one blow, but even with exceedingly bad short circuits close up to the boxes they cause no trouble, and very little mess is made in the fuse itself.

There is also another very important point mentioned by the authors, and that concerns the use of fuses of the tubular type. In all cases where such fuses are used either the tube ends should be sealed up, the whole fuse and terminals enclosed in a case, or care taken to provide that the ejection of the molten metal from the open ends when the fuse blows cannot cause damage to other apparatus in the immediate neighbourhood. I had occasion, a short time ago, to be sorry that we had not taken these precautions in the case of a tubular fuse on one of our boards. This fuse was carrying a normal current of about 100 amperes, and it was situated on a traction board at a distance of some 3 or 4 feet from a generator change-over switch, the top connections of the switch being for lighting and the lower portions for traction. The fuse blew, and the metal was ejected across to this change-over switch, and caused a short circuit across the terminals, practically shutting the machine down. That was with a tin fuse. The amount of the metal for the 100 amperes was possibly three or four strands of something like 14 S.W.G., and at the distance mentioned it caused an arc to be set up between terminals a distance of at least 1¼ inches apart, having a difference of potential of about 450 volts between them. Of course, had that fuse been entirely sealed at both ends, such a thing would not have happened. It also has an important bearing on the fire risk. If the metal can be ejected at distances like that, and in such a molten state, the use of all combustible material round about it should be avoided.

Another very important point is on the mixture, or the purity, of

Mr. Watson. the material of the tin and the lead. At different times I have had a number of tests carried out on the usual commercial tin fuse wire which is obtained for ordinary work, and I have found that with a given diameter of wire, supposed to be of exactly the same quality, the capacity varies enormously. The makers of fuse-wire should therefore pay a good deal more attention to that point.

Messrs. Schwartz and James. Professor SCHWARTZ and Mr. JAMES (*in reply*): Mr. Andrews's experiments afford an interesting illustration of the magnetic blow-out effect in fuses. With regard to the behaviour of fuses blowing with small overloads, it is well known that with certain types of both open and enclosed fuses under these conditions the arc is more persistent than when blowing under larger overloads, and therefore all fuses should in addition to a short-circuit test be tested with a gradually increased load.

With reference to Mr. Russell's contention that a fuse blowing on short circuit explodes due to the pressure of the metal vapour developed in the interior of the fuse, we would suggest that the projection of the metal particles to considerable distances may be accounted for by the molten metal segregating into globules and the arcs formed between the globules raising the metal of the globules to the boiling-point, the emission of this vapour projecting the globules after the manner of rockets, the temperature of the globules being kept up by the combination with oxygen. Mr. Russell's contention is no doubt correct where metals with a solid oxide sheath are concerned. With copper the oxide sheath is soluble in molten copper, and the explanation of the double peak in the pressure rise in the oscillograms is possibly due to the fact that following on fusion the segregation of the metal into globules suddenly introduces a high resistance into the circuit, and the consequent sudden drop in current causes the first peak. In metals with solid oxide sheaths this segregation into globules does not occur at the moment of fusion, but immediately after disruption, and consequently the double-peak characteristic of copper and silver is not observed. The pressure rise at the moment of the final break is common to all metals.

The question of the power behind a fuse on test is an important one, and we quite agree with Mr. Patchell that the pressure is an all-important factor; but we hold that, with a given circuit pressure and the short-circuit current *limited* to the amount the fuse will get when in actual service, so long as the source of supply can give this current for a short time at the stated pressure the actual pressure in kilowatts of the source of supply is immaterial. With regard to the intensity of the short-circuit currents suitable for the testing of fuses of various types, further investigations on the lines of the experiments conducted by Mr. S. L. Pearce in Manchester are required.

We agree that fuses intended for house distribution work would not operate satisfactorily if shorted across the busbars in a central station, but we contend that they would there be subjected to far more severe conditions than they would be required to meet in actual practice. In

reply to Mr. Patchell's queries, Calais sand is purely siliceous, whereas Trent sand is largely argilaceous; the diameters of the wires are given in Table X. in place of the gauges, as the latter are B and S. Messrs. Schwartz and James.

In reply to Mr. Paterson, if the minimum no-arc length is determined in the manner stated, there is no great uncertainty as to the results; if, however, this method of procedure is not adhered to, consistent results will not be obtained.

The conditions obtaining when a metal conductor extending between two fixed terminals is disrupted are essentially different to those obtained when an arc is drawn out between a moving switch-blade and a fixed contact, and we hardly think that Messrs. Russell and Paterson's interesting results could be applied with advantage to fuses.

Mr. Mordey states that it has long been recognised that copper and silver are the best metals for fuses, but at the present time in this country it is difficult to find an enclosed fuse in which these metals are employed, and with open-type fuses the use of the softer metals still preponderates; copper wire can be used down to sizes fusing with 6 amperes.

With regard to the "Caddis cases," we have in the paper distinguished between the *sheath* of oxide which forms around wires of oxidisable metal in open-type fuses and the slag *tubes* formed by the fluxing of the siliceous fillings of enclosed fuses; it is these latter which conduct after the manner of Nernst filaments, while it was to the former that the term "Caddis cases" was applied.

We have had a considerable experience of tinned copper fuse wire, and have not observed any noteworthy alteration in the fusing current produced by the tinning.

In copper wires of small gauge considerable variation in diameter is frequently found in the same coil. This probably accounts for the variation in fusing current found by Mr. Sayers.

In reply to Dr. Garrard, in our previous paper on "Low-tension Thermal Cut-outs" we defined the normal fusing current as follows: "The normal fusing current for a given wire, the length and environment of which are constant, may be defined as the minimum current required to fuse the wire in such a time interval as shall be necessary for the wire to have attained its maximum steady temperature." This definition we have never departed from. For small-size open fuses we have determined the N.F.C. by slowly increasing the current at a given rate, but with large fuses, especially when enclosed too high, a value may be obtained by this method owing to the large time element, hence the modified method of determination given in the present paper. With reference to the time element, there is a good deal in Dr. Garrard's contention that it should be represented by a curve; but it would, of course, be impossible to represent it in this way on the label of a fuse.

Mr. Cramp complains that the results given in general in the paper are not suitable to the designers of fuses. I may say that there is some truth in that contention. These results really are putting into shape the

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experimental work which we have been doing over the last two years for the Engineering Standards Committee, and when these results have been considered by the Standards Committee I think Mr. Cramp will find that they will be definite and valuable for designers. We have purposely avoided making any very definite statements, or drawing up any conclusions, because the matter is in the hands of the Standards Committee, and we do not wish in any way to prejudice their consideration of the case. I think, however, if Mr. Cramp will look at the paper again, he will find that some very definite information is conveyed in these figures. Looking at the particular curve in Fig. 4 on which he based his remarks, he would be able by reference to that curve to see what length of fuse he would have to use in order to secure immunity from fusion on his terminals. Then with regard to the reference to attacking the problem from a more scientific and theoretical point of view. I quite agree that from a theoretical point of view a good deal can be worked out as to the behaviour of a wire up to the moment of fusion, but I would like to make this point very strongly, that we are concerned not only with what the fuse is doing up to the moment of fusion, but also with what follows in the few hundredth parts of a second after fusion has taken place. In actual work so many conditions come in, that a purely theoretical handling of the subject will not lead to any practical results. I would refer Mr. Cramp for further information on this point to our previous paper on "Low-Tension Thermal Cut-outs."

With regard to the temperature of the globules, it is quite true that tin melts at a temperature of 230° C. Mr. Cramp thinks that very likely the globules thrown off by the fuse would influence the photographic plate at a comparatively low temperature. I hardly think that they would influence the plate at a temperature as low as 230° C., which is very much below red heat, and I think he would agree that the temperature of these globules really is high when we come to consider the effect of the scattering of them on the blowing of a fuse of a low fusing-point metal. For instance, take zinc; the metal globules, although their melting-point is low, are at so high a temperature that they go on burning in the air, and will set fire to objects on which they fall. Both Mr. Cramp and Mr. Smith have drawn attention to the calculation on page 74. Now the reason for its form is that it represents the suggestion which we make as to the rating of a fuse which should go on the label, and that "B" is kept in because it represents the permissible full-load current of the circuit, and is one of the quantities which we wish to express on the label. The rating of the fuse should not be limited to the normal fusing current, but should also include a figure expressing the sensitiveness, and possibly also another expressing the time element of the fuse. Our factor of safety is on the current which gives the maximum temperature rise allowed.

Mr. Watson raises the question as to aluminium. We have not dealt very largely with aluminium owing to its action when placed in contact with brass or copper in a damp situation. About two years

back some aluminium fuses from section pillars were brought to my notice which were corroded where the aluminium strip made contact with the copper jaws, owing to the aluminium being highly electro-positive to the copper; this may be reduced by coating the surfaces with black lead or tinning the contacts. For small circular wires the action of the oxide sheath is prejudicial; it holds up the molten metal until it is vapourised. Aluminium also necessitates larger mass being used, and this should be avoided. Silver has not been used very much in this country. Up to about a year ago it was used very largely in Germany; German electricians have recently congratulated themselves on the discovery that copper is better than silver. Messrs. Schwartz and James.

In connection with the use of the term "no arc," it must be pointed out that in general an arc may be said to take place whenever a current passes between two electrodes through a column of vapour. From this point of view an arc takes place (though often of very short duration) each time a fuse is blown. In this paper, however, the term "arc" is restricted to occasions when the severity is such as to cause damage to the terminals; if after blowing a fuse the jaws of either of the terminals are fused together, an "arc" is said to have occurred; if the jaws are not fused (possibly they may be slightly marked, though still quite usable), "no arc" is said to have taken place. As Mr. Cramp suggests, it is quite possible that, with what is apparently a longitudinal field, we may really be getting a field that is to some extent a lateral one, owing to the curving of the lines of force; when an independent coil has been used to produce the "blow-out" field, care was taken to place the fuse in the axis of the coil and as near the centre as possible. In connection with Fig. 11, Mr. Cramp suggests that the longer duration of arc with 20 turns as compared with 10 is possibly due to the increased inductance obtained. This is not probable, because in each case there was extra inductance in the circuit, which was large in comparison to that due to the turns round the fuse.

The inductances given in the paper were measured with alternating currents, and therefore the result in the case of the field coil mentioned by Mr. Cramp will be lower than the calculated value owing to the effects of the eddy currents in the solid iron core. How much less will depend upon the magnitude of the eddy currents produced which will depend upon the rate of change of flux. It is to be noted that this apparent diminution of inductance will also take place when the flux is disappearing in a direct-current circuit containing solenoids with unlaminated iron cores. The numbers given in the paper for inductances in various types of circuit are only approximate, as in addition to varying with the cause mentioned above the values will also depend upon the current flowing in the circuit.

Mr. Smith has pointed out that the pressure rise in an inductive circuit is not nearly so high as would be expected from a consideration of the rate of fall of current and the assumed inductance. The slope of the curve of *rise* of current confirms his idea as to the core becoming

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saturated during the rush of current obtained in short-circuit tests, with a consequent diminution in the inductance—it will be noticed that the rate of rise of current is greater when the current has reached a half of its maximum value than at first, whereas if the inductance had been constant the rate of rise of current would continuously diminish as the current rose. It is worthy of note in connection with Mr. Smith's remarks on the inductance of the cable itself, that pressure rises have been obtained when no added inductance has been used; the pressure rise, however, is small and of very short duration. Mr. Smith's suggestion as to the advisability of experimenting on cables of different lengths, using no added inductance, is a valuable one.

Proceedings of the Four Hundred and Seventy-second Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 12, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 5, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Charles D. Le Maistre.

From the class of Associates to that of Associate Members :—

Clarence Edgar Allen.	Charles F. H. Bayly.
William R. Anderson.	Leopold C. Benton.

From the class of Students to that of Associate Members :—

James T. Becklake.	Andrew Hamilton.
L. B. Boilard.	G. Ollonqvist.
F. W. Brecknell.	L. E. Sitzler.
James Coghlan.	Fred Wardrobe.
Victor W. Gill.	Geo. S. Wilson.
Thomas C. Hall.	Wilfred Yorke.

Messrs. R. Grigg and A. P. Haslam were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Thomas Boyden. | Carl Koettgen.
Frederick Leonard McKeever.

As Associate Members.

William Walne Alston.
Ernest James Cox.
Jonas Henry Crossley.
George Kenelm Field.
Francis Richard Marsh.
Sydney William Melsom.
William Henry Perrow.
Thomas Henry Relton.
Cecil R. Shaw.
Walter Winkworth.

As Associates.

George Alexander S. Atkinson. | William Frain.
Alec Gardner, Captain, R.E.

Donations to the *Building Fund* were announced as having been received since the last meeting from M. B. Byng and Professor J. Epstein ; and to the *Benevolent Fund* from F. Gill, to whom the thanks of the meeting were duly accorded.

Sir William Preece then delivered the following lecture :—

LECTURE: AMERICA REVISITED, 1907.

By Sir WILLIAM HENRY PREECE, K.C.B., F.R.S. (Past President).

(*Delivered on March 12, 1908.*)

I have visited the United States four times—in 1877, 1884, 1893, and 1907. My first visit was official—to investigate the telegraphic system—and the result was the introduction of the telephone to this continent. My second visit was with the British Association to Montreal, but being invited to the States to attend the American Association at Philadelphia, I took advantage of my visit there to inspect the progress made in telegraphs, telephones, and electrical industry generally. My third visit was as a British Commissioner to the World's Fair, at Chicago, and again I was able, through the great kindness of our American friends, to overhaul the progress made in our profession.

My last and recent visit was as the guest of Mr. Andrew Carnegie, to assist in the dedication of his great gift to Pittsburg—the Carnegie Institute—by which education, art, science, and engineering will receive a great increment of propelling force in America. The previous visits were duly reported to this Institution, and will be found in the printed proceedings for each of the years mentioned.* I propose now repeating the same operation upon my visit in April, 1907.

I have crossed the North Atlantic Ocean ten times, including a trip to the West Indies, and have experienced a very great improvement in the character of the ships and in the comforts of the journey. The table on next page gives the Cunarders in which I have sailed, and, for comparison, the first and the last ship of that Company. It is interesting to notice the evolution in length, size, power, and speed; but it is in the provision of food that the improvement is chiefly marked, for the fare on board the *Carmania* allowed now in the third-class saloon is quite as good as that provided in the first-class saloon thirty years ago. Reading-rooms, writing-rooms, card-rooms, and delightful *lounges* are additional luxuries of space. Baths and lavatories exist in excess, and not in the serious deficiency of the seventies, when one had to form a unit in a long *queue* and waste long periods in waiting for one's turn subject to the jeering smiles of passing lady passengers!

* *Journal, Institution of Electrical Engineers*, vol. vii., 1878, p. 22, "The American Telegraph System."

Ibid., vol. xiii., 1884, p. 570, "A Visit to Canada and the United States in the year 1884."

Ibid., vol xxiii., 1894, p. 40, "Notes of a Trip to the United States and to Chicago, 1893."

	Date.	Tonnage.	H.P.	Length B.P.	Breadth.	Depth.	Speed. Knots.	Days.
Single Screw—				ft.	ft. in.	ft. in.		
Britannia	1840	1,162	740	207	34 4	24 4	8½	14·38
Abyssinia...	1867	2,960	3,100	358	42 0	29 2	14·4	10
Bothnia	1874	4,556	3,250	420	42 3	36	13·8	8
Aurania	1882	7,268	9,900	470	57 3	38 6	17·0	8
Etruria	1884	8,119	14,500	500	57 3	40	19·5	7
Twin Screw— *Caronia*	1905	20,000	21,000	650	72 6	43 9	18·0	7½
Triple Screw— *Carmania*								
Four Screw— *Mauritania*	1907	32,500	70,000	760	88	60	26	5

But, above all, we in the *Caronia* passed through three severe gales without the necessity of having "fiddles" on the tables, and without any serious reduction in our numbers at meals. The twenticth century long ships ride over the waves without pitching, and the ample bilge keels check rolling, while the distribution of cargo, coals, and water ballast secure better balance and trim. Were it not for fogs crossing the Atlantic would be a luxury, but the low melancholy wail of the deep-toned foghorn, periodically emitted, makes a fog an incentive to suicide. If radio-telegraphy and submarine signalling were universally applied the foghorn would be unnecessary. Submarine signalling is in its infancy, but the *Caronia* and *Carmania* are both fitted up, as well as the new Cunard Leviathans, the *Lusitania* and the *Mauritania*.

The *Caronia* and *Carmania* are sister ships, but the one is fitted with reciprocating engines, and the other with turbines (Parsons). Their dimensions and propelling power are precisely the same, but their propellers and revolutions per minute differ in number, size, speed, and position.

The *Caronia* has two screws of 24 ft. diameter at the edge of the blades, and the *Carmania* three of 14 ft. diameter. The revolutions of the former are 80 and of the latter 185, but the immersion of the turbine-driven propellers is so much deeper that they never come out of the water, while those of the *Caronia* in stiff gales do come out and "race," and give those nasty vibrations which led one of our past presidents, now dead and gone, the brilliant Scudamore, to write :—

> "O, the racing of the screw! What the mischief shall I do
> With this most malignant beating of an ill-intentioned screw?
> With the lifting and the thumping,
> And the shifting and the bumping,
> And the most unpleasant jumping of an evil-minded screw?"

This experiment of the Cunard Company has been a momentous event. It has led to the adoption of the turbine on their new Leviathians, and there is no doubt that the advantage of the removal of "racing" has had an immense influence in forming their judgment.

The travelling public can only be grateful to the Cunard Company for adding so much to their comfort.

New York.

The change in the sky-line as you approach New York is very marked. The confined space in the lower end of the old town has made land so valuable that it has forced building upwards, and New York is now covered with Towers of Babel. My hotel, the Belmont, has twenty-seven floors, five of them being below ground. It is 368 ft. above the ground—higher than St. Paul's. It is steel framed like all these new buildings. It is beautifully equipped, thoroughly well managed, and a most comfortable house to stay in—though it does perceptibly vibrate in the upper floors in strong gales. My room was on the seventeenth floor, and I had from my window a fine panorama of the East River, with its great bridge, and of Long Island. Messrs. Singer were commencing in Broadway a record building of forty-one floors, and I had a grand opportunity of inspecting the foundations. It has now been completed and occupied. It is 612 ft. high! I also inspected the new McGraw Buildings—the home of the Electrical World and all its allies—a fine and handsome ferro-concrete building, and I spent much time in the lofty homes of Telegraphy and Telephony. One of the most interesting and picturesque edifices is the office of the *New York Times*. Its lofty, conspicuous, busy tower raises its head in the upper part of the town with the graceful lines of a classical Italian structure. It reminded me of Giotto's tower in Florence. It has thirty stories, six being below ground. It is remarkable for the fact that the subway railway of four lines passes through the basement, and that it is built over Times Square station. This station is 4 miles from the Battery and 4 miles from 145th Street, the other end of New York. It is thus geographically the centre of Manhattan.

The backbone of Manhattan Island is a bed rock of gneiss—a primary rock apparently free from earthquake disturbances. All the new steel-framed and ferro-concrete buildings are based on this rock. The highest building in New York from foundation to top is the above-mentioned "Singer" building. European heights are—

	ft.
Cologne Cathedral	512
St. Stephen's, Vienna	446
St. Peter's, Rome	435
Salisbury	404
St. Paul's	365

Some of these Brobdingnagian emporiums contain, during the busy hours, ten thousand people. Their entry and exit together with their intercommunications is a great problem of lifts and staircases. It is astonishing how well it is done. The lifts are wonderfully rapid and numerous,* and I was transported to my seventeenth floor in Hotel

* There are nine in the Hotel Belmont.

Belmont in 30 seconds, quicker than we ascend from the entrance hall to this theatre—only one stage.

The fear of fire in these great buildings, or "skyscrapers," is soon dissipated, though since I returned home a building which I visited has had an ugly experience. It is supposed to have been incendiarism, excited by foreign political animosity, but it created no panic nor involved loss of life, though it caused much loss of property. The new "Singer" building has also had a fire on its fortieth floor, but it was quickly subdued. The rapid clearance in busy hours of such populous hives in case of panic is a knotty point, but there seems no misgiving and no want of confidence in their stability and safety. Wood is now made fireproof. American metallurgists and engineers are agreed that the proper use of concrete, cement, and paint is an adequate preservative against decay of iron. When the old Chicago Post Office was taken down, after standing for twenty-five years, its wrought-iron beams were found to be in perfect condition. A similar report was made of the Palace of Industry in Paris, which was built of iron in 1862 and demolished in 1900. Iron was used in the construction of the obelisks, and there may be seen to-day, apparently as strong as ever, the iron clamps which held together the great stone blocks in the Parthenon at Athens. Steel-framed concrete buildings withstood the earthquake in San Francisco. I am, however, thankful that we are not yet driven to extend skywards in Westminster.

There are no bells in the Hotel Belmont. All orders and communications are sent and received by telephone. There are 813 telephones in this hotel, and from your bedroom you not only order your breakfast or your tea by telephone, but you can speak all over New York and to Chicago. I spoke to Philadelphia and to Boston with perfect ease. On each floor there is a clerk who controls the telephone and attends to all your wants. You mail your letters in a letter box near your door, from which they descend by gravity from every floor to a mail box in the central hall, which is cleared by the postman on his regular rounds.

A rapidly growing application of electrical power is the system of cleaning by vacuum. It is known there as the Kenney Vacuum Sweeping System. There is no need for brooms or mops or dusting brushes. A vacuum is produced electrically in the basement by the ordinary supply currents, and permanent pipes are laid into every room of the building, to which a brass connection is made by a flexible hose, having at its end apparently a rake but without prongs. Dust is thus bodily extracted from carpets, curtains, and even clothes, and drawn down to a dust receiver in the basement, whence it is collected and removed. Even cornices and picture frames are cleaned. It is used by the ordinary housemaid. It is astonishing to see how rapidly the process is carried out and how thoroughly it does its work. It is in actual operation in the Belmont Hotel, where it keeps the place beautifully clean. It seems to me excellently well designed for generating station use, where dust is so essentially matter in the wrong place, and much superior to the compressor system so much in use now.

Though New York is a smokeless city, for they are compelled to burn only anthracite coal, there is much sea fog, but not the dismal, black, choky fog of London. One great feature—very evident from my lofty perch—is the multiplicity of thin white streams of steam emanating from every large building. It is curious that in New York isolated plants are apparently the rule, and the Central Power Scheme which has kept the Parliamentary Bar over here alive for several sessions, and is likely to occupy the attention of some of us for another one, is not indigenous to America. The whole of the external electrical supply of New York is in the hands of one enterprising company, who do the work as well as it can be done, and have splendid load-factors; but they have not put down the isolated plants. This, of course, is a financial question, and not one of inefficient or insufficient supply. The isolated dynamo is offensive to the central station man, but it may be an object of desire to the user.

New York since my last visit has distinctly advanced in artistic taste. The private buildings are very fine and the public ones magnificent. I know no finer building in Europe than the Public Library in Forty-second Street, and the parks with their museums, the riverside drive, and the environs generally, are picturesque and beautiful.

The most interesting edifices to us in New York are the home of the United Engineering Societies (the gift of Mr. Carnegie), the Engineering Club, and the McGraw Building. The first houses all the engineering institutions except the Civil Engineers. It cost $2,000,000 (£400,000), and was built within the estimate. The three founder societies are the Mechanical Engineers, the Electrical Engineers, and the Mining Engineers, but all engineering institutions will be welcomed as tenants. It is a tall building of thirteen stories above ground, and each institution absorbs one whole floor. The main auditorium, or theatre, seats one thousand people, and there are two smaller meeting-rooms for papers and discussion.

Adjoining the Engineering Societies' building is the new club house of the Engineers' Club. It is another lofty, handsome building of thirteen floors above ground, overlooking Bryant Park and the great Public Library. It contains magnificent suites of offices and rooms, club and private, and numerous well-equipped bedrooms, together with the inevitable bar and *café*. There are three lifts from basement to roof. The tenth floor contains breakfast and private dining-rooms. A stately banqueting-room with accommodation for three hundred is on the eleventh floor. The kitchen and service-rooms are on the twelfth and thirteenth floors. There is a roof garden, where in summer meals and refreshments will be served.

In the basement are the barber's shop, boot-cleaning room, offices, storeroom, cellars, and general conveniences, and in the sub-basement heating, lighting, ventilating, and refrigerating plant. It was opened immediately after my departure homeward, but it was finished, and I was able to appreciate its luxury and completeness as a club. Would

that we had such a club in Westminster! Every American engineer is quite proud of it, and with reason.

The McGraw Building is a fine example of reinforced concrete work. I thoroughly inspected it while it was being built, and now (1908) it is occupied. It is in West 39th Street. The neighbourhood is becoming the great business centre of New York. The building has eleven stories, but it is only 159½ ft. above the basement floor. It is the publishing office of the *Engineering Record*, *Electrical World*, *Street Railway Journal*, and *Chemical and Metallurgical Industries*. The bed rock (gneiss) was found close to the surface, and the excavation required was only 20 ft. deep. The concrete columns are strengthened with steel angles covered with concrete for fireproof and preservation purposes. They are founded on the rock, as required by the Building Code of the City of New York.

A very artistic spirit in the establishment of these three buildings was that of Mr. T. Comerford Martin, who in New York acted as my guide, philosopher, and friend.

PITTSBURG.

The main object of my visit was the opening of the Technical Schools of the Carnegie Institute in Pittsburg. There is a remarkable difference between the United Kingdom and the United States in their attitude to education. Here we expect the Government to do everything, there they expect the millionaire to usurp the position of the Government. There is no Supreme Board of Education or Minister of Education. Every State has its own system, and the work of university training and technical education is the result of private munificence. Drexel, Armour, Rockefeller, and Carnegie have distributed their millions with free hands. Pittsburg has already received from Mr. Andrew Carnegie $20,000,000 = £4,000,000, but the management is in the hands of a splendid board of trustees—all Pittsburgers.

The Carnegie Institute covers 4 acres, but other 32 acres given by the city have been allotted to the Technical Schools. The main building has a façade 400 ft. long and a depth of 600 ft. The buildings externally are severe and simple but classical, without any effusive ornamentation, while internally they are more ornate, and when the bright gilding tones down will be very effective. They are roomy and well designed. The music hall, where the ceremonies were held, is acoustically wonderfully good and quite handsome. The library is well stocked and will eventually contain 1,500,000 books. It is unique in this, that it contains a children's library and reading-room. It is also a circulating library. The art galleries of pictures and sculptures, and the museums of natural history, palæontology, geology, and mineralogy are being rapidly filled with objects of value and interest. On April 11th last the fifth department—technology—was added, and the whole place was dedicated to literature, science, and art. The ceremonies were impressive, the speaking admirable, and the whole function most successful.

The buildings of the Technical Schools were only adapted for the first-year students, but as the course will be of four years it will be another three years before the buildings will be complete, for they are finished as each year is finished. It is intended to provide for four thousand students; there are now fifteen hundred. Building operations for all are well in hand, but there seems little chance of finality where the appliances of science are progressing with such rapid strides. The slides which I have the pleasure of exhibiting will give you a better idea of the place than any verbal description.

We were first welcomed by the President of the Institution, Mr. Frew, and were then received by the Mayor of Pittsburg and by Mr. and Mrs. Carnegie. We then inspected the library, museum, and art galleries. After lunch the dedication ceremony took place, and Mr. Carnegie gave an admirable address, with sparkling extempore flashes of wit and wisdom.

This magnificent gift was presented by the donor with the following concluding words: "Take, then, people of Pittsburg, this gift from one who owes Pittsburg much, who loves her deeply, and would serve her well."

I want to chronicle the fact that I delivered an address on "The Connection between Science and Engineering," and that I received a degree of LL.D. from the Western University of Pennsylvania, known locally as "Wup." It is the oldest university in the U.S.A., whose local habitation will now be the Carnegie Institute. I am going to deal with the question of technical education in America in another place.

Pittsburg is more interesting to us as being on the bituminous coal-fields, having natural gas fuel, the great manufacturing centre of the iron and steel, coal and glass interests, and the home of the Westinghouse factories. Pittsburg was so named to commemorate William Pitt, Earl of Chatham, the then Premier of England, whose son, the great William Pitt, was born in the same year—1759—that Pittsburg was founded by General Forbes. George Washington was an officer on his staff. The blockhouse that was erected there that year still exists as a relic of the past. The Allegheny and Monongahela rivers unite there and form the Ohio, which then joins the Mississippi in Cairo and flows to the sea at New Orleans. In 1796 its population was only 1,400, it is now over 750,000. It is the fifth city of the U.S.A.

Some of us were handsomely entertained by Mr. Westinghouse, not only in his works but in his private house. His works embrace the older ones of air brakes as well as the more modern electrical industry. I find that in 1906 the production of

	$
Electrical and auxiliary manufactures was ...	45,000,000
Air brakes	10,000,000
Underground cable and wire	71,000,000
Railway switch and signals	5,100,000
Total	$131,100,000

This was for *all* Pittsburg, but the greater portion was turned out by the Westinghouse Company.

Since my visit the great financial crash took place, and these works suffered trouble, but the crisis was surmounted, and I hope and trust that the Westinghouse Works are in full work again. They are very extensive, admirably arranged, controlled, and managed. The long galleries full of busy bees are easily inspected from bridges, which cross them at the head of each department. They are thoroughly well ventilated and well warmed in winter. The index system of records is a pattern for every one, and the drawings of any one of two or three hundred thousand orders executed are rapidly obtained. The works are managed by the best experts in America. They have a local technical society, and print their valuable papers, read for mutual help and record.

TELEGRAPHY.

My report of 1877 was almost exclusively on telegraphy.

The progress in telegraphy at each period of my visits is shown by the following table :—

	1877.	1884.	1893.	1907.
Mileage of wire ...	300,000	433,726	769,201	1,321,199
Offices open	11,660	13,600	21,078	24,760
Messages ...	28,500,000	40,000,000	66,591,856	148,804,000
Capital ...	$60,500,000	$80,000,000	$123,000,000	£140,000,000
Income ...	—	—	$24,978,440	£32,856,406

The chief result of the first visit was to establish sound reading, and to introduce quadruplex working in the Post Office system.

In 1884 the only novelty was Delany's "Multiplex," sending six messages simultaneously on one wire, which we imported and introduced into the Post system.

The Western Union Telegraph Company had adopted the British Wheatstone system, and I saw circuits working very well from New York and from Chicago to New Orleans.

The active warlike competition of 1877 and 1884 had ceased in 1893. There was no war of rates. The only form of rivalry was good service. Very great improvement in construction was visible, and underground work became prominent. In Great Britain we had started in 1837 with underground wires, and have maintained that system on a large scale ever since. The Americans, on the contrary, were forced most unwillingly to place their wires underground by fierce legislative

enactments, but they have now found that they were wrong in opposing it so strenuously. Their cities were made hideous by several rival lines of poles streaming down their principal thoroughfares. It was much better in 1893. There was no telegraphic improvement of any note. Duplex and quadruplex working were in full swing. But the typewriter for received messages had become quite fashionable. Operators provided themselves with machines, and the telegrams were delivered printed in bold Roman type—a great improvement on the usual hasty scrawl.

There is one condition of business in the United States that makes telegraphy there more profitable than in the United Kingdom. It is the existence in the message supply of what we should now call a good "message load-factor." In the United Kingdom we have but one uniform Greenwich time. People deal with their letters everywhere about the same time. There is a peak of telegrams in the morning, and another, a smaller one, in the afternoon. But in the great breadth of the United States, where there is a difference of time between New York and San Francisco of 3 hours, the stream of messages is virtually continuous. We may say that the message load factor in the United Kingdom is 2,* and in the United States 6. Their great distances and belated mails make telegraphy more necessary and instantaneous communication of less consequence. The result is that these circuits carry, on the average, three times as many messages in a day's work as we do.

In 1907 the system of Wheatstone automatic working has been greatly improved practically by Mr. Barclay, the assistant general manager of the Western Union Company, impressing the typewriting machine upon both the sending and the receiving ends. An ordinary typewriter typing a message actuates electrically a punching machine, which punches a paper tape in the ordinary way. This punched strip sends dots and dashes into the line in the usual Wheatstone way, so that the conductor is transmitting currents on the Wheatstone system. The receiving instrument is actuated by these currents, and reels out bold Roman type printed on the usual received copy forms, which is delivered to the public. It does this at the rate of 100 words per minute, and while I was in New York one circuit to Boston cleared off 1,097 messages in 9 hours. This system has been adopted by the Western Union Telegraph Company in preference to the Buckingham or the Murray.

There were the following Barclay circuits at work at New York:—

Chicago	6
Boston	2
Philadelphia	2
Buffalo	1
St. Louis	1

Pittsburg and Atlanta were about to be added.

In this system the operator does not require to know the Morse

* This means that if the whole day's work were continually in operation the average would only occupy two hours of the twenty-four.

alphabet nor the manipulation of a key. She needs only to be a typewriter. The instrument does the rest. It requires little work, and it solves the much vexed question of skilled labour. As a matter of fact, it aided materially to defeat the recent strike in the Western Union Company from August to November last, for plenty of female operators were available to carry on the work after a very short training in an ordinary typewriting establishment. It has reduced the cost of working such circuits by one half, and it turns out perfect senders in a fraction of the time required to form a skilled Morse operator. The system is extending very fast. The Western Union Company is rapidly installing it on all trunk lines, and if I ever visit America again I shall probably find it the most popular service. It is very accurate. On a Chicago circuit eight hundred messages were sent with only two repetitions.

I also inspected the Rowland system, which is on trial on the Postal Telegraph system between New York and Boston. It is a quick automatic printing system dependent on the synchronous movement of the apparatus at each end. It works octoplex—four operators at each end having in succession the use of the single wire for a fraction of a second, at rapidly recurring intervals on Mayer's system. It utilises alternating currents. I was not so much impressed with this system as with the Barclay. It is more complicated and dearer to work. It is a mistake to imagine that speed of working is a great desideratum in telegraphy. I commenced my telegraphic career in 1852 with Bain's chemical recording system, which attained a speed of 1,500 words a minute. The determining practical speed is in the handling of messages as they come in. A speaker should not speak at a rate of more than one hundred words per minute. Messages rarely pour in at greater speed than this. It is found in practice that such a speed keeps down the work on each circuit, so that it can be manipulated practically at the highest speed and the lowest cost. If the messages pour in at a greater pace than this then another circuit is necessary. Thus the unit of a telegraphic system is a message, and it is the number of messages per hour and the number of working hours per day (the message factor) that determine the number of circuits per trunk line.

The growth of telegraphy has everywhere been checked by the growth of telephony, but the expenses have not changed in the same direction. On the contrary, they have increased. The combined companies in the States have found it necessary to revise and increase their rates. The average increase adopted has been only 2 per cent., but many anomalies have had to be regulated, and increments of from 30 to 66 per cent. were made. It is remarkable how quietly this was received. It was a pure business transaction, and the Americans are essentially business people. One cause of the greater cost was, however, the reduced working capacity of the human operator, who, in my first visit, averaged twenty-five messages per hour; now the average is only seventeen. Hence the commercial value of mechanical systems worked on the automatic principle.

Our old friend, Mr. Delany, has designed an "autodot transmitter," which reduces the difficulty of learning to work the Morse key. It has two levers, one for dots worked by the thumb and one for dashes worked by the forefinger, moving horizontally with very light pressure. The number of dots made depends on the period of pressure. Thus any one with a musical ear can work a Morse key without any fatigue and with much greater accuracy. It is not so dependent on skill, and its use tends to cheapen operating charges.

He has introduced also an automatic system in which he has utilised the static charge. His receiver is the Bain chemical recorder. He has also introduced a secret system which prevents tapping or overhearing. The autodot key is used. It is very ingenious. The impulses set up by the key are sifted or disintegrated by a relay at the receiving end, which will respond only to its own tuned key.

I saw these two systems working with great accuracy.

"What would they say in England" if the Post Office ventured to raise the rates? They are not very chary of criticism in the press even now, but the severity of the remarks depends much on the paper and the party in power. I read a month ago the following extract from a Unionist paper: "In the Post Office management of the telegraphs we have a striking illustration of the danger of permitting the State to control a great industrial undertaking. When the telegraph companies were bought out in 1869 it was confidently prophesied by the Government of the day that the purchase would result in a large annual profit, which would suffice to pay off the whole purchase-money in twenty-nine years. Actually no profit was made at all after the first two years, and the accumulated losses since incurred by the taxpayer now amount to many millions sterling. These losses tend to grow greater year by year, and the annual loss to-day is well over a million pounds. With this ugly fact before it the nation would do well to think many times before embarking on a far more serious venture."

No reference whatever is made here to the *per contra*. The Press, with its ruinous rate of 2d. per 100 words cost at one time £600,000 per annum. Messages are now delivered free. Nearly every village in the country has its telegraph. Innumerable offices are kept open all night. The railway companies have an immense free service over the whole Post Office system. There is no capital account, and all extensions and renewals are charged to revenue. The annual income taken over was £600,000. It was for the year ending March 31, 1907, £4,369,227! The annual loss *on paper* may be one million per annum, but the above *per contra* will wipe this out and leave the most magnificent telegraph system in the world the free asset of the British public—an asset which I once valued at £30,000,000.

TELEPHONY.

In 1877 I witnessed the birth of the Bell telephone. In 1884 I saw it developed into a strong and rapidly growing child. In 1893 it was a robust youth; and now in 1907 I saw it a matured man, with enemies

buzzing around it to filch from it its good name and its well-earned reward. There are seven thousand opposition independent companies playing about. They have secured many important franchises and have installed very many telephones, but I failed to obtain reliable statistics and was not able to visit one of their exchanges. The Anglo-Saxon loves competition, but he has yet to learn the lesson that reliable telephone working is essentially the function of one single uniform system under some controlling power, whether commercial, municipal, or Governmental. The Post Office is an illustration of the advantage of this single authority as regards letters and newspapers, and when the telephones of the United Kingdom are entirely in the control of the Government, as they will be in 1911, then we shall have an ideal system controlled by the public, when the public grasps the conception that it is itself a part and parcel of the system, doing half the work and amenable to the same rules and regulations. Now it loses its temper, writes to the press, and causes irritation in the other half of

TABLE I.

Growth of Telephones.

	1884.	1893.	1907.
Miles of wire ...	115,255	440,793	7,468,905
Telephones ...	162,787	552,720	3,553,418
Subscribers ...	123,625	232,140	2,741,367
Exchanges ...	1,325	1,351	4,889

TABLE II.

Telephones in Service, January 1, 1907, in American and European Cities having over 1,000,000 Population.

	Population.	Telephones.	Telephones per 100 Population.
London ...	6,580,616	130,101*	1·98
New York ...	3,437,202	279,047	8·12
Paris	2,660,559	62,370†	2·34
Berlin	1,888,848	83,824†	4·43
Chicago ...	1,698,575	126,436	7·44
Vienna ...	1,674,957	27,541†	1·64
Philadelphia ...	1,293,697	95,914	7·41

* Includes Post Office system.

† Estimated. Based on same percentage of gain as was attained in 1905.

the business, with the result that the work done suffers. Knowledge, forbearance, and mutual assistance are more essential in telephone working than in any other social function we exercise.

Table I. speaks for itself. It shows the gigantic growth of the Bell

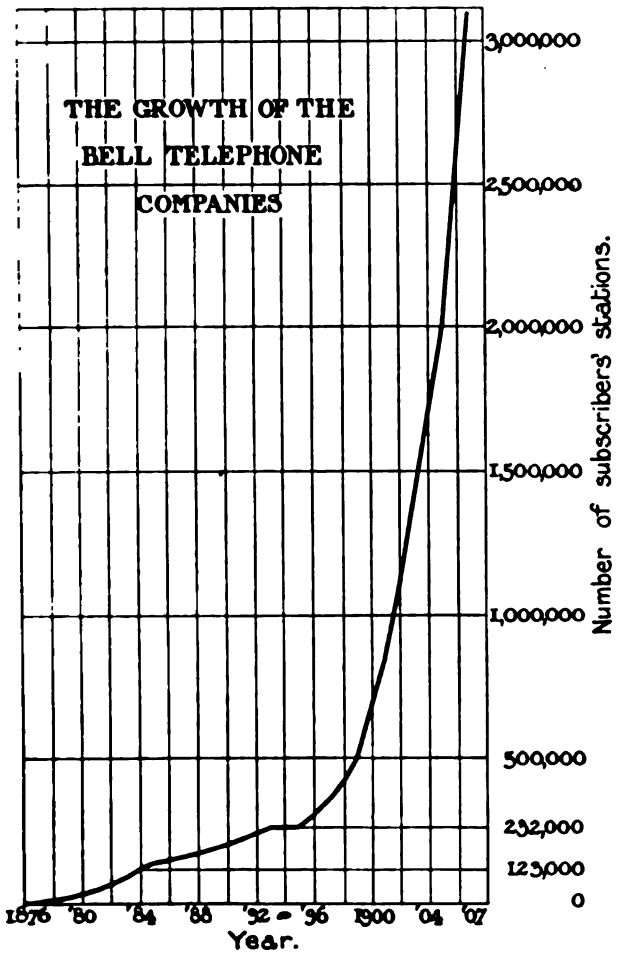


DIAGRAM 1.

telephone system in the United States. It does not include Canada or the work of the Independent Companies.

Table II. gives an interesting comparison of big cities in Europe and America.

Diagram 1 shows the growth in subscribers' stations up to January 1, 1907.

The type of instrument used has practically not changed. Transmitter and receiver, whether made in America or Europe, are very much the same in type and efficiency. The telephone receiver sprang almost perfect from the brain of Bell, but the transmitter has been modified by Edison, Hughes, and many others, and is found in various types not materially departing in efficiency or form from that used in 1893.

The metallic circuit, which was only partially in use in 1893, is now universally employed over the whole Bell system.

Here we divide our circuits into *local*, *junction*, and *trunk*, additional telephones in the same building being called "extensions."

In America the *local* term remains the same, the *junction* is called "trunk," and our *trunk* is called a "toll" or "long-distance" line. The switchboards have not materially altered. The predominant feature remains the multiple board. The divided board which I described in 1893 has not taken root. But the rapid growth of the system in large cities has raised the question of the practical economic limit to the size of the multiple board. No board has yet been made in America to exceed ten thousand "jacks" for one multiple section. We have, however, to provide for a greater number than ten thousand in London as well as in New York.

It is found in modern practice that each operator answers on the average one hundred circuits, and during busy periods it is possible to place three operators at each section. I have seen four, but this is exceptional. Thus a ten thousand switchboard would require one hundred operators distributed over thirty-three sections when working at full pressure, but this is a very rare occurrence. It is much more common to see only two operators, or even one per section, and in light hours one operator can manage several sections, for the number varies very much with the hour of the day. The number of calls at one section which can be dealt with directly without the assistance of some other exchange is comparatively small, and the cost of a complete multiple board is so great (about £1,000 per section) that it has been found possible to work with partially fitted sections by treating all calls as "trunk" calls. Thus in addition to "trunks" and "junctions" involving other distant exchanges we have to consider "transfers" in the same exchange, and therefore a separate and distinct "connection board" in another or even the same room. It is thus practical to contemplate exchanges of 50,000 subscribers.

In New York Mr. Carty has introduced what he calls a "Partial Multiple Board," and in London Sir John Gavey introduced a similar board. The outgoing calls are largely in excess of the local calls, so that the use of complete multiples is not economical. There is only one complete multiple section on the main board in New York called "B," which has also all the incoming transfers and junctions. The incoming subscribers' "answering jacks" are distributed partially but methodically and consecutively over the other "A" sections, all of which are connected together by "transfers." The subscribers' sections consequently have

the out-going "jacks" multipled upon them, and the junction or connecting boards wherever they may be have the subscribers' "jacks" multipled. Local calls outside those immediately allotted to an operator are dealt with by connecting lines between the sections on the main board.

The call is made automatically by the subscriber when lifting his receiver. The section operator who sees it inserts an answering peg in this "jack" and asks, "Number, please." When obtained she connects it directly with the number if on her section, or to the proper transfer if on some other section, passing on the number to the other operator who completes the transaction. The automatic visual signal system makes this possible and practical.

I mentioned the fact that in the Belmont Hotel in New York there are 813 stations and that each bedroom is a station. There is a local switchboard in the clerk's room on each floor and a central one in the main hall. This central switchboard is connected by forty junctions with the Telephone Company's central suburban exchange, and from each bedroom command is obtained of the whole telephonic system—New York local, suburban, and long-distance. Greater New York has a population of 4,550,000.

It is very gratifying to find that the automatic visual signal, which has expelled the magneto and the ring-off, has become universal. It was my invention, introduced in the Post Office in its first exchange in Newcastle in 1880, and used in every exchange erected subsequently in its system. I am sorry to say that, not having secured this invention by patent in this country, I have failed to secure the credit of being its author, although my paper of 1893 and published books fully record the principle. It was introduced by the American Bell Company with the central battery system using glow lamps instead of needles without any acknowledgment. It is true that they used different means, but the principle is that introduced in the Post Office system.

It is astonishing how the necessity for special buildings and the use of electric power has increased. A ten thousand multiple board with central battery and glow-lamp signals requires 500 amperes on the average and 2,000 amperes on emergencies. The telephone exchange thus becomes a power house of considerable capacity.

I was not able to inspect an automatic switch board. There was not one at work near New York. I do not believe in automatic switches except for small private branch or local exchanges. They assume the lines always to be in working order and the called subscriber always at his post! They are really more costly to work than manual boards, for they want so much highly paid technical attention. They are certainly less reliable. The failures of an automatic switch in Connecticut were found to be fourfold of a manual one, and there was no practical difference in speed of connection, which, by the bye, I found to be on the average 20 seconds. However perfect they may be, they do not dispense with the presence of operators, and I failed to observe in all the reports that I read of the meetings of the independent companies any mention of the automatic switch. Human intelligence

is essential for junction and trunk working as well as for inter-office work, and this embraces more than half the average talks of a subscriber. Automatic switches have been coincident with telephony. They were tried and abandoned in Sweden long ago.

A vexed question here is the rate question, but in America it is settled in favour of the measured rate. This system was started in Buffalo, and was described by me in my paper of 1884. Every time the subscriber used his telephone he paid 6 cents per message up to five hundred, then 5 cents up to one thousand, and 4 cents for all over one thousand.

The business unit is a *talk* of 3 minutes, but the practical unit of management is *the number of talks per circuit per hour*. This determines the number of circuits distributed to each operator, and is the factor that regulates the working expenses, and therefore forms the basis of the rate charged for each 3-minute talk, or *toll*, as it is called. If we dealt with local calls only the selection of a rate would be simple, but as the largest proportion of the calls are transferred by junctions and trunks elsewhere, much more capital is involved, many more operators invoked, and the determination of a remunerative rate becomes a difficult problem to solve.

The flat rate—a simple annual rental—is fallacious. It assumes equality of use all the year round by every one. The busy broker pays the same as the lazy lodger. It is an unfair mode of charging, and unjust, for the man who is always replying to calls pays the same as each one who originates the call. It also induces unnecessary talks, and therefore wastes both capital and labour—a heinous economical offence. It impedes expansion, for necessarily the flat rate must be high for the small user. It retards efficiency, for it tends to occupy the circuits with frivolous calls when they are really wanted for important calls. It is bad finance, for it does not exact payment by result, and it makes the small user pay for the work done by the great user.

Hence every one in the United States of America has come round to the conclusion that the toll rate is simple, fair, and just. It has been adopted by our Post Office, and it is being assailed in the way all novelties, especially if proposed by a Government Department, are assailed in this party distressed country. It involves the use of meters or counters to record each talk by the depression of a key by the operator who manipulates the switchboard at the exchange. Every user can very easily check the meter by depositing in a box a counter for each talk completed. A month or two's experience will instil faith in the accuracy of the meter.

The average number of talks per day per circuit in America is six, but it is easy to get twelve talks per hour per circuit, and if the daily load-factor is three,* then there would be thirty-six talks per day. Now, on the average there are as many calls one way as the other, and therefore each subscriber pays for half the talks, say eighteen per day for three hundred days in the year. This means at 1d. per talk

* By *day-load-factor* I mean the number of hours the line would be occupied if it were in continuous use.

£22 10s. per annum. This is taking three times the average of the busy American who uses the telephone certainly more than the Englishman.

Large users are now getting their service done *for less than cost price*. Indeed, it is done at the expense of the small users. Is that just?

At Buffalo now a sliding mode of charging by results is adopted; everybody pays for each oral message he sends. Every time he uses the telephone he pays either 4, 5, or 6 cents, according to the number for which he guarantees—6 cents for each message under five hundred, then 5 cents up to one thousand messages, and 4 cents above one thousand.

Since 1900 the construction of circuits has been revolutionised. Lead-covered paper cables are made carrying 600 circuits. Even pole lines carry 600 pairs of wires instead of 40. This is due to the employment of aerial cables. Load lines on Pupin's method have increased the capacity of underground work. There is now a good working system of circuits from New York to Philadelphia, which are nearly 100 miles apart. Underground work improves the service and reduces the cost of maintenance. The work has become much more solid and permanent, thanks much to Mr. J. J. Carty.

The telephone is not used as much in America for telegrams as it is in the United Kingdom. Here it is a very great convenience. Being virtually already a branch of the Post Office, subscribers can get a telegraph office at all hours of the day, and they can send and receive all their messages *without any loss of time*. They need not even write them down; they can answer at once. Monthly statements are sent by the Telephone Company of the number and cost, and payment is made, as a rule, at once. It works remarkably well.

I was interested to see portable telephones in use in restaurants. There are plugs in the walls like those we insert for portable electric lamps, and when at lunch or dinner you want to speak to any one in New York, a portable telephone is placed by your plate, and you can eat, drink, and converse at the same time with your wife at home or your partner in your office. I saw a great deal of this done. These portable telephones are much used for sick-rooms, as, indeed, they are with us.

The Telharmonium.

Dr. Cahill's new apparatus is a synthetical method of building up all that makes for pure and emotional music. It is a practical mode of demonstrating the absolute accuracy of Helmholtz's theory of the quality of sound. It is a mechanical, physical, electrical, and telephonic mode of making and distributing music over a wide area.

The keyboard is like that of a piano or organ, but each key is a simple switch which completes an electric circuit. A low-voltage continuous current operates a relay bringing into action a fundamental note and certain selected partials compounded of alternating currents of variable frequency.

The action of the relay is mechanical. It lifts a balanced strip of

wood along which are fixed contact pieces which set up the fundamental note and its required partials. The keys respond promptly. Indeed, the action is virtually instantaneous. You see sparks and flashes following the movements of the sliding bars, and you hear clicks but no music. The energy is entirely in the electrical form. It is not heard until the very last operation is performed upon an iron disc at a distance. The manipulation of the keyboard and the use of pedals and stops set up electric waves which are the exact counterparts of the sonorous aerial vibrations it is desired to excite. These waves are transmitted through insulated wires buried in the streets all over a certain district in New York. The player controls everything, and discourses sweet music of a character hitherto undreamt of. He, by depressing a key, selects automatically the fundamental note and its required partials—in other words, he forms the waves, regulates their duration, modulation, loudness, and feeling. These waves are distributed in their resultant form, and, exciting a Bell telephone receiver, set up sonorous vibrations which distribute to all listeners refined and beautiful music.

There are 144 inductor alternators in the New York machine. A long shaft rotates with uniform velocity. It has mounted on it 144 toothed rims which correspond with each fundamental note it is desired to transmit. The rotation is produced by a continuous-current motor of 185 H.P. The *pitch* is the frequency, the *quality* or *timbre* is the form of the wave, *modulation* of loudness is obtained by varying the strength of the currents, *expression* by the use of stops which mix the tones.

The effect is quite wonderful. The tones of a piano, violin, violoncello, harp, trumpet, clarionet, flute, and all kinds of music separate or in orchestral form are manufactured in electric currents of varying frequency, amplitude, and duration, and the result is a new music. It requires great skill to perform, but the purity of the notes and the quality of the music emitted is superb. The receiver that produces the music is a large Bell receiver, and the effect excites one's wonder at the marvellous property of the little iron diaphragm of reproducing the innumerable sonorous vibrations of the human voice or of the well-equipped orchestra of the Opera House.

This is the marvel of the telephone. I never use a telephone without thinking of how little we know of the molecular disturbance of a conductor which conveys those currents that distinguish the voices of our friends and relations separated by great distances, and that produced the "concord of sweet sounds" that excited my admiration in New York. Even the flame of an arc lamp by this means emits music.

The inventor of this new music is Dr. Thaddeus Cahill, and his original plant was fixed at his home, Holyoke, Mass.; but I am not much impressed with its commercial value, for the time, labour, and money expended on the plant is very great and the performers to manipulate it must be very highly skilled. I cannot hear of its making any progress.

Electric Lighting.

In 1884 the electric light was so little advanced that I had to refer only to the objectionable practice of street arc lighting by means of overhead wires excited by dangerous high-tension currents. As a matter of fact, we were almost as well advanced in the United Kingdom, for the first generating electric light station in the world had been at work at Holborn Viaduct since January, 1882. The City Temple was the first place of worship and St. Martin's le Grand the first post office to be illuminated electrically. It was, however, very different in 1893. Public street lighting had been adopted by practically all towns and villages in all parts of the United States. Arcs were being used very much for shop lighting and for advertising. Internal glow-lamp lighting was very general. Isolated plants were, however, the fashion.

Table III. gives the position of affairs in New York when I was there last year. It speaks for itself and shows the immense progress made. In Table IV. we show London.

The city of New York is made up of five boroughs :—

	Population, 1900.	Area in Square Miles.
Manhattan	1,850,093	22
Bronx	200,507	39
Brooklyn	1,166,582	66
Queen's	153,000	124
Richmond	67,021	37
	3,437,203	308

Table III.

The New York Edison Company.—Total Installation, April, 1907.

	Customers.	Meters.	Glow-Lamps.	Arc Lamps.	Heating Appliances.	Storage Batteries.	H.P. Motors.	16-C.P. Equivalents.
					k.w.	k.w.		
*Manhattan	54,185	68,035	2,535,268	33,602	739	4,296	144,750	4,931,529
*Bronx ...	2,352	3,254	121,195	1,898	51	15	2,452	168,549
Yonkers ...	1,311	1,461	35,786	456	5	1	550	50,072
*Brush ...	88	—	2,242	314	—	—	10	5,091
Totals ...	57,936	72,750	2,694,491	36,270	795	4,312	147,762	5,155,241

* City of New York.

The New York Edison Company, so ably managed by Mr. J. W. Lieb, jun., has virtually the monopoly of electric supply in Manhattan—a long island, densely populated, 13½ miles long, and about 1¾ miles wide.

TABLE IV.

London Electricity Supply.

	Plant Installed.	Maximum Load.	8-C.P. Lamps Connected.	Units Sold.
	Kilowatts.	Kilowatts.		
Borough Councils	54,197	34,911	2,328,253	51,179,778
Companies ...	141,055	88,338	5,953,982	127,063,504
Total ...	195,252	123,249	8,282,235	178,243,282

It distributes energy on the 3-wire continuous-current system at 240 and 120 volts.

It has four generating stations—

Duane Street,
East 12th Street,
West 26th Street,
140th Street, Bronx,

supplying direct to their immediate neighbourhoods and one great modern Waterside station, generating high-pressure 3-phase alternating currents at 6,600 volts transformed down to 240-120-volt continuous currents at fifteen sub-stations.

I made a careful inspection of this great waterside station which many of you saw in its incipient stage. Now it is a standard American generating station of great size. It has been duplicated already. There are two separate and independent stations alongside each other. It is fitted right up-to-date with every approved apparatus and process. I was much impressed by the action of a controlling officer in the inspection gallery, who has command not only of the whole combined station but of all the outgoing mains and the other generating stations, and who can so distribute the outgoing load that the pressure can be maintained very constant on each feeder and the load well distributed to the different sub-stations.

The two stations combined handle 150,000 k.w. The old station (1902) has only a few turbines of small units, but the new station (1907) will be completely equipped with 8,000-k.w. turbo-generators, the present favourite unit.

While I was at New York (April 20, 1907) the elasticity of this system was severely tested. A 5,000-k.w. turbo-generator broke down, and a 4,000-k.w. reciprocating plant failed at the same time. The two stations were working in parallel. The pressure dropped perceptibly for some minutes in the upper part of the town, but it was not affected in the lower part, and the system was soon restored to its normal

condition. It was a grand test of the flexibility and reliability of the New York Edison system.

I give a diagram below showing a maximum load on a winter's day.

There is another allied company, called the United Electric Light and Power Company, supplying 2-phase, 60-~ alternating currents at 7,500 volts, stepping down the voltage and changing the frequency at

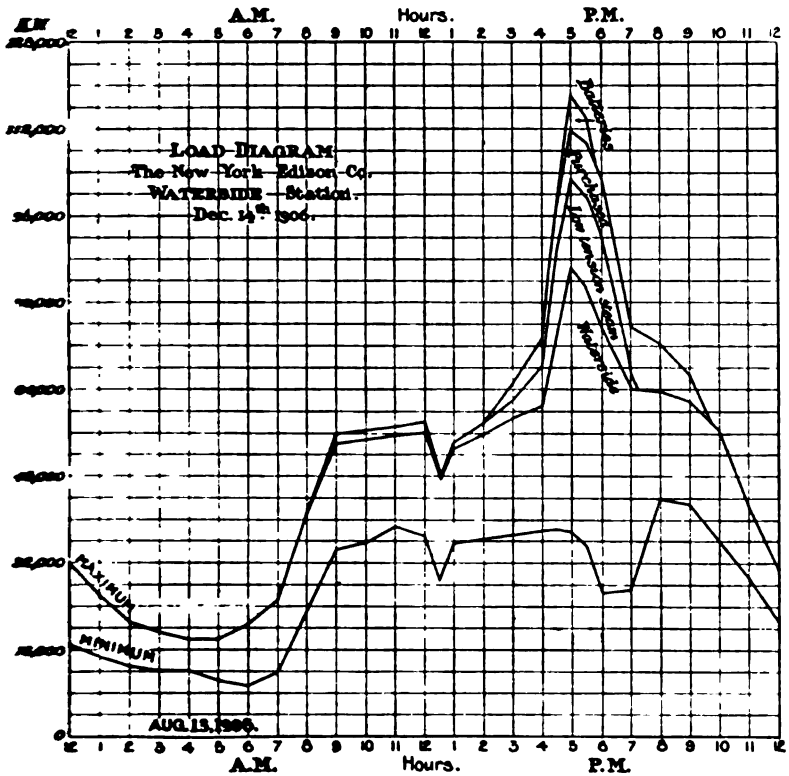


DIAGRAM 2.

sub-stations by motor-generator sets to the normal distributing voltage. Its generating station is on the East River at East 29th Street, not very far from the Edison Company's waterside station, which it has occasionally helped to get over sudden and high peaks. Thus on December 14, 1906, the waterside station supplied up to 86,400 k.w., the four low-tension steam stations up to 102,400 k.w., the 7,500 volt supply up to 112,000 k.w., and the batteries up to the top of the peak. The waterside station is now duplicated and is independent of external help.

The Curtis turbo-alternator is in great fashion in America, principally because it is American, but being vertical it occupies smaller

space than the Parsons. The American is very patriotic. "America for the American" is their commercial battle-cry. They often employ inferior processes simply because they are American.

However, in this case the vertical Curtis turbine has justified its selection for some very accurate and careful tests of an 8,000-k.w. engine supplied to the Fisk Street station, Chicago, gave 14,132 k.w. at 750 revs. per minute with a water-rate consumption of 13·13 lbs. per kilowatt-hour, which was equivalent to 9·85 lbs. per E.H.P.-hour, the steam pressure being 194 lbs., the superheat 150° F., and the vacuum 29·31 in. This was on a twenty-four hours' exhaustive test which was made while I was in the United States by Messrs. Sargent and Lundy, the well-known consulting engineers, of Chicago.

The charges for electrical energy are based on a sliding scale varying with the load factor. They are—

10 cents per unit, including the third and fourth hours.
7½ cents per unit, including the fifth and sixth hours.
5 cents per unit all hours in excess of six.

Contracts on agreement terms are entered into with large consumers under guarantees. This gives the supplier a much freer hand than the legal restrictions defined by our unfortunate Act of Parliament which we cannot get reformed.

I mentioned the *New York Times*' "skyscraper" as one customer who used electric energy for every purpose connected with the daily manufacture, printing, and issue of a newspaper.

In comparing the tariff for light with ours at home, it must be remembered that in America it is a charge for "light" and not for electric energy as with us. The American companies not only renew the lamps, but they maintain them in thorough efficiency. Lamps are removed when they deteriorate too much, and deterioration in time is unfortunately a serious characteristic of carbon lamps. It is not so serious a question with the new metallic filaments.

I visited the Electrical Testing Laboratory in East 80th Street, New York, which is under the charge of Dr. Clayton Sharp—an extremely well-equipped and well-manned institution for exact measurement and for commercial electrical testing. It is also employed for research—the basis of all electrical advance. It is a business enterprise supported by the electrical industry. In the year ending April 30, 1905, thirteen million lamps were tested, and the effect has been to improve the quality of the lamps manufactured in the United States. They are very much superior to those manufactured in this country. The laboratory is supported principally by the manufacturers themselves. We hope, with the aid of the Board of Trade and the National Physical Laboratory, to produce the same results in this country. The Engineering Standards Committee is about to take up an investigation of the efficiency of the new metallic filaments and to frame a specification and its necessary standards. The tantalum and tungsten lamps are making great progress in both hemispheres.

I saw tested some tungsten lamps for street lighting that were very promising. They had short, thick filaments, taking 10 volts and 5 amperes, or absorbing 50 watts. Their candle-power was 40. Of course they were connected in series, and it was proposed to excite them 200 in series with 2,000 volts.

The prominent development of the electric light in America is its use for advertising. New York is illuminated with glaring sky signs. The streets are one blaze of light by night, but the effect is not artistic. It is, however, commercial, for it aids materially the increase of the load factor, and it is therefore a very profitable and welcome customer to the purveyors of electrical energy. The flame arc is as popular there as it is with us.

Electric Railways.

Electric railways were making a good start in America in 1893. They were practically all on the same pattern—trolley wires, continuous currents of 500 volts, rail returns, supplemented by heavy copper rods buried in the ground. The third rail system was introduced on the intra-mural line in Chicago. In the power houses countershafting was the rule. The two chief questions on their trial were: first, the use of one motor and bevelled gearing per car, or two separate motors, one on each wheel axle; and second, the removal of the contact rail and return to a slotted conduit underground.

There are now three great railway systems working electrically in New York merged into one system, called The Interborough Rapid Transit Company:—

1. The Metropolitan Street Railways.
2. The Elevated Railways.
3. The Subways.

The New York Central and Hudson River Railroad is also equipping its suburban and main lines with electric traction.

1. The Metropolitan Street Railway means the surface tramway system of New York and Bronx. It extends northward 33 miles from the Battery, and embraces about 500 miles of single track. It is impossible to conceive a more favourable position for such a service than that in Manhattan. The tramways pass through a densely populated district where the business is all done at one end and the domestic and social conditions are found at the other. There is a wave of population transported in one direction in the morning and in the other direction in the evening, while a large permanent and continuous exchange takes place during the whole day. Its earnings are considerable, but its finances have been strangely "pingponged," and disastrous panic has followed since my visit. The service in Manhattan is of the metallic circuit and conduit type, which has been so satisfactorily followed in London by the London County Council. That in the northern section is trolley overhead and much is only single track, for the northern district is but sparsely populated.

There are over 200 miles of conduit track. The pavement is asphalt, granite sets, and wood block—the last seems the most favoured. It is very expensive, but the end justifies the means. The conduits are divided into isolated sections at approximately half-mile distances apart. There are two generating stations on Manhattan, transmitting alternating currents at 11,000 volts 3-phase and 25 ∿ to sub-stations, where they are transformed down to low-tension continuous currents for distribution through the conduits to the cars. The units are 3,500 k.w. each reciprocating engines directly connected to the alternators. The load factor varies from 60 to 65 per cent. The service works well and the fares are very moderate.

2. The Elevated Railways of New York frequently carry 1,000,000 passengers a day. Their motive power was completely changed from steam to electricity in 1903. The carrying capacity was increased 33 per cent., and the working costs were reduced from 55 per cent. to 45 per cent. of the gross receipts.

The generating station on East River is equipped with 3-phase alternators driven directly by reciprocating engines at 11,000 volts and 25 ∿, which is transmitted to sub-stations by underground mains. Here rotary converters supply continuous currents at 625 volts to the third or contact rail, the return being by the track. It is a very fine station and has four circular stacks, 17 ft. diameter, and 278 ft. high.

The units are 8,000 H.P. with 5,000-k.w. alternators. The net output reaches 700,000 k.w.-hours per day. I did not visit this station but I am told that turbines have been or are about to be installed there.

Each six-car train consists of four motor-cars and two trailers. Each motor-car has two motors of 125 H.P.

There is no doubt that the change from steam to electric traction has been a very great success, and it has met with universal approbation.

3. The Subways. This is an ideal metropolitan underground electric traction service. It extends from one end of Manhattan to the other. It has four lines, two for local stopping traffic and two for rapid express service. There are 48 stations, 23·57 miles of subway and elevated structure, and 72·61 miles of single track. The subway is generally built with steel columns supporting the street such as we can see in London under Kingsway, and such as was inaugurated in Buda-Pesth in 1898. Reinforced concrete has also been very much used. It has nothing to interfere with or impede its service but its own traffic. There is no difference in fare between local and express trains. It works well, and is from the public point of view a great success.

I was taken over the Subway by Mr. Deyo, the chief engineer.

A peculiarity of the line is that there are short acceleration inclines at each station on both roads to assist the necessary rapid start. The following condition in the contract is noteworthy: "The railway and its equipment constitute a great public work. All parts of the structure where exposed to public sight shall be designed, constructed,

and maintained with a view to the beauty of their appearance as well as to their efficiency."

The power house is on the Hudson River at West 58th Street. Its capacity is 100,000 H.P. There are six sections each complete in itself with its own chimney, each serving twelve boilers. The engines are connected directly to 5,000-k.w. alternators. The chimneys are supported on steel columns, which gives additional boiler space. Thus all the boilers are on one floor level. Forced draft is used. The turbine, as with us, is coming into favour owing to its extreme flexibility. There are eleven 5,000-k.w. reciprocating engines and alternators at 25 ∿, and four 1,250-k.w. turbo-generators at 60 ∿ for lighting. The distribution is by 3-phase alternating currents at 11,000 volts to sub-stations, where they are transformed down to 625 volts and converted by rotary converters into continuous currents for traction at eight sub-stations. The current is picked up on a third rail and returned on one rail of the track. It is curious that this dangerous live-rail system instead of the safe two-rail system employed on our Metropolitan system has been adopted in America.

The rolling stock does not differ very much from that introduced on our Metropolitan lines. The Subway cars seat fifty-two persons. The local stopping trains are made up of five cars, three being motors; the rapid express trains of eight cars, five being motors. The latter run at 2½-minute intervals. The motor-cars have two 200-H.P. motors on one truck.

The Subway signal system on their express line is the electro-pneumatic block and interlocking system, worked automatically without signalmen. It has been partially introduced in London on the Metropolitan District Railway. It makes for safety and reliability, and it tends to increase the train capacity of a railway. The removal of the working of the mind of a tired signalman removes the principal cause of accidents on railways. Stopping trains can be started at one minute intervals on the New York subway line. The moving energy on the switches and interlocking gear is pneumatic pressure, the controlling power is the electric current. The circuit is completed mechanically by the passing train.

Air compressors are fixed at certain stations along the line, which are pumped up by continuous-current motors served by a special circuit. They automatically maintain the pressure at about 60 lbs. in 2-in. pneumatic tubes. This pressure, switched on or off automatically by the passing trains, lowers the signals behind. The signals are both semaphore arms and colour signals illuminated by two glow lamps and coloured by glass screens moved in front. On each home signal-post there are two semaphore arms and lamps placed in a vertical line, the upper being the home signal itself and the lower a repeater of the forward distant signal. Thus the lower signal is always the repeater signal of that in front of it. The lower signal of 3 (Diagram 3) is a yellow light showing 2 to be at danger, while 4 is at green. The danger or imperative "stop" signal is

always *red*. A *yellow* light on the distant repeater means "caution." It indicates that the distant signal is at danger. A *green* light always means "clear" or "proceed." The signal lighting is by a special alternating-current circuit independent of that used for traction. There is also an emergency cut-off on every station platform to warn and stop all passing trains if there is danger or accident ahead, and a "trainstop" if a train attempts to pass a signal at danger. The former is a precaution against panic and accident. The second track rail is used for these electric signal purposes. The block sections (Diagram 3) have an overlap which is the section—invariably 800 ft.—between the home signal and the next distant signal. It is usual to make the absolute block section between home signal and home signal, but on the Subway the passing train automatically clears the overlap of 800 ft. and enables the following train to come on to the next forward distant signals. Thus the driver of the train always knows the signals in both the sections in front of him. The distance between these signals is 800 ft., and between trains 2,400 ft. There is always a clear block section existing behind a train. It is a perfectly

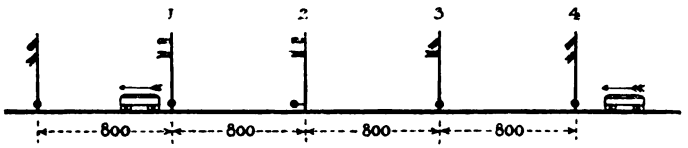


DIAGRAM 3.

safe system where the speed of the trains is limited to, for the local, 15 miles per hour, and to 30 miles for the express where the overlap is longer, but it very much increases the number of signals to be maintained. On the other hand, it dispenses with a great many signalmen —a much dearer commodity.

NEW YORK CENTRAL AND HUDSON RIVER RAILROAD.

This railway starts from the Central Station and skirts the Hudson River, and is the great north artery from the City. The main line is being equipped completely for electric traction to South Croton, a distance of 34 miles on the Hudson Division, and to White Plains, 24 miles on the Harlem Division. This is called its *electric zone*. It is an interesting experiment, for it is the first main line in the country that has seriously tackled main line working in all its branches by electricity. There will be four tracks throughout, so as to separate the suburban from the through traffic. Hence heavy electric locomotives became necessary for the through coaches between New York and Croton and White Plains.

The electric system at the power house is 3-phase alternate currents of 11,000 volts and 25 ∿, which are distributed to eight sub-stations, where they are transformed down first to 450 volts, and then acting on rotary converters generate continuous current at 660 volts, which is

supplied to the third contact rail. The return is by the track rails. The live or contact rail is very well protected along its whole length by a wooden sheathing. It is a bullhead rail, 70 lbs. per yard, insulated with porcelain blocks, and fixed outside the track. The contact is made on the lower surface of the rails by curved contact shoes.

The New York power house is at Port Morris, but a second one is at Yonkers—each being on the waterside and on the railway for coal supply and ash removal. They are identical in general design, and are cross-connected electrically for mutual help. Each will have installed 30,000 k.w., and they have each a space capacity for 60,000 H.P. The coal bunkers are built over the boilers, so that the fuel descends by gravity to the mechanical stokers (Roney's). Their capacity is 3,500 tons. The stacks (two) are 15 ft. 6 in. in diameter, and 250 ft. high. Curtis turbines are installed, the unit size being 5,000 k.w. Each is to contain six sets, connected directly to 3-phase alternators of 11,000 volts and 25 ∿. The exciters are also turbo-generators of 150-k.w. capacity, furnishing continuous currents of 125 volts, and having a battery of 74 cells and 1,200 ampere-hours capacity as a regulator and stand-by. In fact, every known successful process of producing economical results and securing safe and efficient service has been adopted. It is worth noting that the value of uniformity, harmony, and standardisation is so much appreciated for self-help that all the railway power houses in the neighbourhood of New York adopt 3-phase alternating currents of 11,000 volts and a frequency of 25.

The chief novelty introduced is the separation of the switch apparatus in buildings separated from the engines and boilers by a distance of 40 ft. This is for safety, security from fire, and better service where high tension and oil are in use. Here also is placed the battery and its apparatus.

In each place there is a load dispatcher's office, where the proper distribution of power over the system is regulated both during regular work and in case of accident and trouble. A record board indicates by visual signals the apparatus and lines in and out of service. There is a distinct telephone service interconnecting power houses, sub-stations, and train dispatchers over the whole electric zone.

Each sub-station is equipped with a battery to smooth out momentary excessively heavy calls for current, and to be prepared for momentary interruption of supply of energy from either power house. There is also a special gallery for lightning arresters. There are three rotary converters of either 1,000 k.w. or 1,500 k.w. in the case of the Grand Central and Mott Haven sub-stations.

The locomotives weigh 95 tons, and carry four series-wound motors, one on each driving axle, giving a maximum of 3,000 H.P. The armatures are mounted directly on the axles, and the field magnets are attached to the locomotive frame. They are designed to accelerate at 1·5 ft. per second, and to drive a train weighing 500 tons at 60 miles an hour.

The cars for suburban service are of steel, and will seat 64 persons

They are fitted up on Sprague's multiple-unit system. The motor-cars have two motors of 200 H.P. each on one bogie.

Most careful experiments were made by the railway company at Schenectady upon an experimental line of 6 miles to determine the relative efficiency of steam and electric locomotives. The latter gave superior results. The time required to reach the speed of 50 miles per hour was in the former 203 seconds and in the latter 127 seconds.

The signal system is virtually the same electro-pneumatic block and inter-locking system as that on the Subway, but the signal-posts being in the open country are more massive and striking.

The preliminary tests all tend to show that electrical traction will be more economical than steam traction, but we shall wait anxiously further experience of real and completed work, for our experience in London is not so promising as regards costs. This, however, admits of explanation.

Electrical traction makes for quick acceleration, shorter intervals between trains, frequent stops for local service, independent lines for express service, the removal of products of combustion, purer air, and more general comfort. All these points support the doctrine pursued in America that competition is to be checked by the development of suburban traffic by electric traction.

The New York Central Railway in 1902 decided to adopt the electric system. They had the man to rely on to carry it out (Mr. W. J. Wilgus), and they did it in no half-hearted way. They went the "whole hog" without hesitation, and now they are very near completion.

The electrical portion has been in the very competent hands of Mr. B. J. Arnold, of Chicago, and Mr. F. J. Sprague. Mr. Katte is the resident electrical engineer. The contractors are the General Electric Company.

I am not quite sure that they were wise in adopting the continuous-current system, for the alternating current has superior advantages. At the same time the weight of American experience supported them. It is quite certain that a great mistake was made in London, but this was entirely due to the importation of foreign influences. Important experiments with alternating currents are being made in America on the New York, New Haven, and Hartford Railways, and in England on the London Brighton and South Coast Railway and the Midland Railway, which will infallibly solve the problem. The experience in Italy continues to be most satisfactory, and Germany is very actively developing the system. My own faith is unshaken in the merits of the alternating current for traction purposes, and my belief that the 3-phase, from the purely electrical point of view, is superior to the single phase. At the same time the single phase has distinct mechanical advantages, which may give it practical superiority. We shall soon have the problem solved.

Wireless Telegraphy.

Wireless telegraphy was scarcely discussed at any of our meetings. As a business it is frosted out. No one talked about it. I spoke,

however, by long-distance telephone with Mr. Fessenden, who was at Brant Rock, beyond Boston, and I was very sorry that I could not accept his invitation to visit him on his transocean station and see some of his very practical experiences.

Considerable trouble arises from the use of the American Morse alphabet on the other side of the Atlantic. The adoption of the European code would be a wise movement.

Standardisation.

I had a long interview with Mr. Halsey, the editor of the *American Machinist*, on the question of weights and measures, which has been under considerable discussion out there. The American engineers are very conservative over the retention of the British inch. They fully concur in the acceptance of the metrical system for physical, chemical, electrical, and generally for scientific purposes, for science is so cosmopolitan that it demands a universal language of terms and units. It is, however, different where we deal with the applications of science in the engineering world and when we enter the workshop. The Anglo-Saxon workman is wedded to the foot rule. His sense of touch makes him appreciate and understand the thousandth of an inch, for it is just the difference between a good and a bad fit. The closest metrical analogue is the fortieth of a millimetre, but this is only an approximation. Neither the *metre* nor the *inch* is a natural unit. The metre is known to be quite wrong, and the only definition of the inch is "three barleycorns in a line."

There would be no difficulty in working either in metres or inches if the latter were only an aliquot part of the former, but unfortunately their relation is only expressible by an interminable decimal fraction. If the metre were exactly forty inches all difficulties would cease. But this can only be done now by changing the metre or the inch or by a little give and take on both sides. It is an international question. The proposal to make the metrical system compulsory seems scarcely within the range of practical politics at present, for the Anglo-Saxon race of manufacturing engineers is nearly unanimous against it.

General Remarks.

It is quite impossible to draw any comparison in economic or practical results between the United Kingdom and the United States. The climate in the two countries is so totally different that the lethargic Cockney on one side of the Atlantic becomes the mercurial Yankee on the other, and *vice versâ*. The accumulation and circulation of wealth, the value of money and commodities, the activity of life, the pressure of social existence, the cost of living are on different sides of the datum line.

There is no reason why there should be any difference in practical progress in one country more than in the other. Our experience is the same, our literature the same, and our science. Mutual intercourse is

easy and frequent. We are always received there with the warmest hospitality, a great characteristic of the American, and we endeavour to reciprocate. My visit was not shadowed by a cloud even as small as a man's hand. The weather without was most inclement and execrable, but it did not affect the sunshine within. I was received with open arms everywhere, and everything was freely placed at my disposal. I should like to express my thanks to all, but their number was legion. It was a thoroughly enjoyable and appreciated visit.

The Institute honoured me—their sole honorary member now—by putting me in the chair at their opening meeting in the New Engineering Society's building, and I felt quite at home.

The new magnificent Cunarders make Atlantic crossings a luxury, and there is no more healthy inspiring and energising trip than a visit to New York in late spring or early autumn.

The PRESIDENT: Gentlemen, you will evidently agree with me that our hearty thanks are due to our Past-President for the magnificent display of energy that he has exhibited this evening in giving us this long and interesting account of all that our American friends are doing in matters that so much interest us.

The resolution was carried with acclamation.

The meeting adjourned at 9.53 p.m.

ARTIFICIAL LOAD FOR TESTING ELECTRICAL GENERATORS.

By R. K. MORCOM and D. K. MORRIS, Members.

(*Received from* BIRMINGHAM LOCAL SECTION, *October* 31, 1907, *and read at Birmingham March* 11, 1908.)

The question of artificial load is one which is often under consideration by manufacturers and electrical station engineers, and simple though the problem is, there seems to be little information of a practical nature to enable the designer of such plant to avoid the errors of his predecessors.

Of all methods of obtaining a load for testing purposes probably the water resistance has been most used, and the first portion of this paper will treat of the use of water resistances.

The theory of the flow of current through conducting masses and laminæ can be worked out mathematically for various ideal forms, and deductions of a useful kind can be made to apply to the less ideal conditions of practice. Such deductions, however, require some checking by experiment, as boundary conditions are apt to confuse calculation.

The quality of water to be used is, of course, the first consideration. It is necessary to find its specific conductivity. A knowledge of the chemical properties of the water is a useful guide to its conducting properties, as illustrated by the following experiment :—

Steam from an engine was condensed in a surface condenser by means of canal water of high conductivity. The specific resistance of this pure condensed water was taken, canal water was then added by 1 per cent. at a time, and a curve of resistance was obtained. The resistance was found to fall in a very regular manner, so that with a standard apparatus the presence of impurity in the condensed water could readily be detected and its quantity estimated.

Where superheaters are in use the impurity will probably be due to leakage from the condenser tubes, and the percentage of leakage water can be immediately calculated (see Fig. 1). If superheaters are not in use, it is possible that priming from the boilers will vitiate the results.

A great deal of work has been done by various chemists on the conductivity of water containing mineral matter in solution, and some neat practical applications and deductions have been brought to the authors' notice by Mr. Pollard Digby, who will shortly be publishing some particulars of his work.

It is also necessary to know the correction for temperature. The resistance-temperature curve is not a straight line (see Fig. 2). For practical purposes it is useful to consider the correction as a per-

centage reduction from the resistance at 60° F. for the intended rise of temperature, say 70° F.

The following table gives some approximate characteristic figures :—

Source.	Degree of Hardness.	Mineral Matter in Solution.	Specific Resistance at 60° F.		Factor for 70° F. Rise.
			Per cm.3	Per ft.3	
	Deg.	(Parts in 100,000.)	Ohms.	Ohms.	Per Cent.
Distilled	—	—	600,000	20,000	—
Condensed from an engine	—	About 2	66,000	2,170	—
Birmingham tap water ...	3·2	6·2	13,200	435	50
50 per cent. Birmingham tap and 50 per cent. Birmingham canal	—	—	965	32	—
Birmingham canal ...	52	143	435	14	50
Blackburn water	—	—	17,000	560	—
Glasgow water	—	Particulars supplied by Mr. Digby	17,500	580	—
West London water ...	—	—	2,800	92	—
Rugby water	—	—	2,400	79	—

In 1904, Mr. J. P. Kemp* published results giving corrections for samples heated by direct current and alternating current. The divergence of the results is probably due to gradual solution of iron in the former case. This action causes a fall of resistance beyond that due to temperature, because the higher the temperature with a given current the less the amount of cooling water to dilute the iron solution. In the same article is given the useful figure that for a rise of temperature of 70°, approximately, 5 gallons of cooling water per kilowatt-hour are required. Where possible salt or soda should not be used to increase the conductivity, but the plant should be designed to use the most abundant local supply.

Without any special treatment of the problem of current flow in the water, it is useful to make one or two simple deductions from the general case. First, a very large body of water cannot give a high resistance even when the electrodes are very far apart. Secondly, if the tank be long in proportion to its cross-sectional dimensions the extent of the electrode immersion makes very little difference to the resistance, provided that the area of the electrode is not very small compared with the cross-sectional dimensions of the water. If, however, the distance between the plates be small then their area of opposition has a great influence on the resistance.

In this connection it should be noted that proximity to the side of the tank has a great effect with narrow plates in large tanks, as illustrated by the following experiment (see Fig. 3).

* *Electrical Magazine*, vol. i., p. 86, 1904.

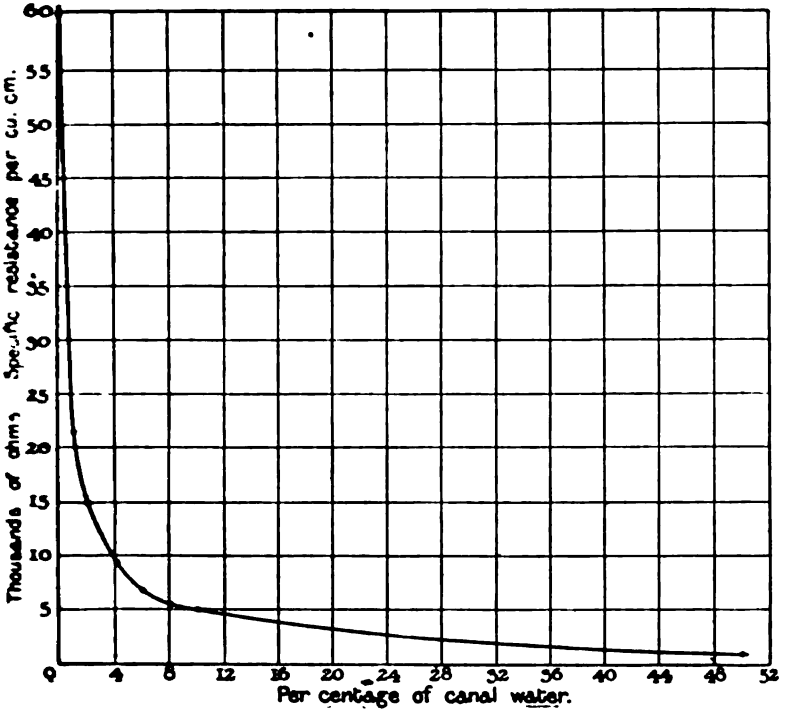


FIG. 1.—Specific Resistance of Condenser Water Diluted with Canal Water at 60° F.

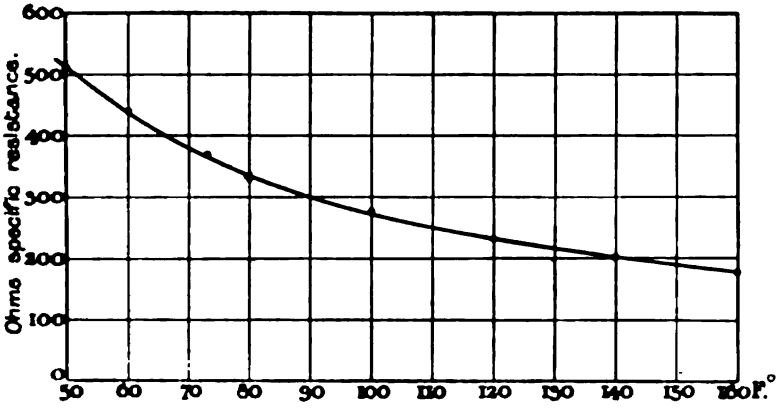


FIG. 2.—Temperature Variation of Resistance of Canal Water.

The resistance in position A is 50 per cent. greater than in position B. This is due to distortion of the lines of flow. Part of the distortion is equivalent to shielding the back and sides of the plate, an effect illustrated by the following experiment (see Fig. 4) Assuming the current with plates as at A to be equal to 100, the current in case B is equal to 95, in case C to 81, in case D to 76, and in case E to 57 (Fig. 4). This effect gives one means of varying the load. The position of the plates for this experiment was that marked B in Fig. 3.

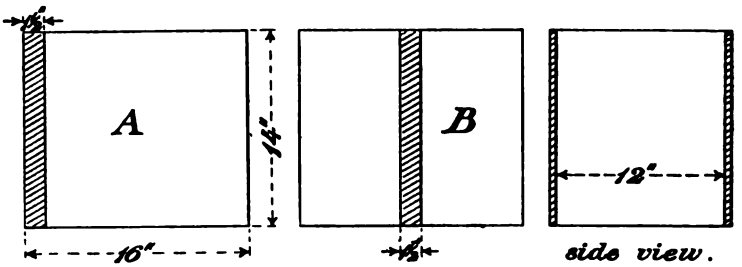


FIG. 3.—Experiments showing Effect of Proximity of Sides on Resistance between two Narrow Plates, ½" wide.

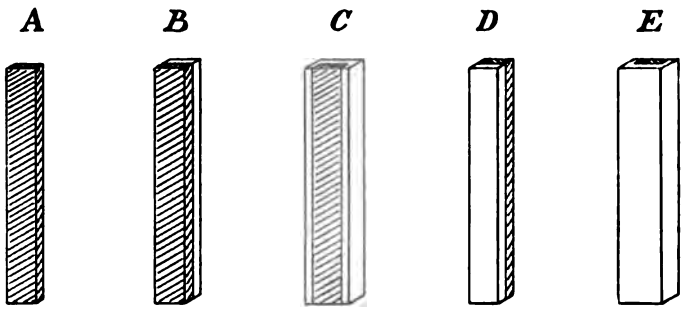


FIG. 4.—Experiments showing Effect of Shielding.

Another convenient method of reducing the load from a given tank is by dropping diaphragms between the plates. As an example the following experiment (see Fig. 5) shows the effect in a particular case. Current as at A being 100, current as at B is only 26·5.

Various modifications of the baffle method will suggest themselves by which the resistance of the path may be increased without upsetting the cooling arrangements or complicating the tank, but the possibility of charring by excessive voltage drop in a short length must be kept in mind. The proximity of the plates to the side of the tank is also a factor in the permissible volt drop per foot of water.

It is found that where the line of flow from the electrode along the tank-side differs but little in length from the shortest line, the voltage drop per foot should not exceed 600 volts, and should be lower than that unless the walls are well insulated and free from metal. This point must be watched with high-tension work, and also in low-tension work where plates that are close together are carried near the side of the tank. A further limiting condition indicated by experience is the maximum permissible current density per square inch of an iron electrode. It will be found advisable not to run at greater densities than 1 ampere per square inch. Trouble from bubbling and rapid corrosion is likely to occur if this be exceeded.

Very much of the foregoing may appear so simple as to be obvious, but it is the neglect of these simple points that often causes a great waste of ingenuity and of money.

The dimensions required having been determined, the materials must be chosen.

Mention has already been made of iron electrodes and wooden tanks in connection with the experiments, and the reasons in their

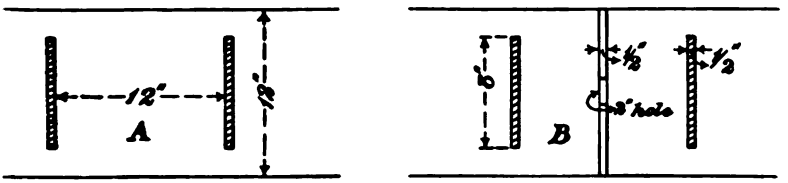


FIG. 5.—Experiments showing Effect of Diaphragm.

favour are strong ones. Wooden tanks are cheap and easy to obtain; they can, with proper precautions, be made durable and water-tight, and as the sides can be rendered practically non-conducting, there is no difficulty in obtaining light loads. Metal tanks, on the other hand, are either expensive or perishable, and light loads are hard to obtain owing to the low resistance path afforded by the walls, unless unduly large tanks are used.

Cast-iron electrodes are cheap and satisfactory, though scrap metal of various sorts may in certain cases be substituted for sake of convenience.

The success of wooden tanks depends largely on the method of construction and the proper attention to details. The following is the description of a tank (Fig. 6) which has done excellent service :—

The dimensions are 7 ft. × 1 ft. 6 in. × 1 ft., and it is used for high-tension work. The sides and bottom are constructed of good spruce, tongued and grooved; all joints are tarred and caulked. Sides, ends, and bottom are made double of 1¼-in. timber, the two layers being built up at right angles, as shown in the sketch. The whole is screwed together in such a way that no screw comes within ¼ in. of the water, and all timber is tarred all over.

The water inlet is through a canvas hose brought over at the outlet end, and carried along the bottom of the tank for its full length.

The outlet is over a sectional weir 6 in. from the end of the tank, and then through a hole in the bottom of the tank. One trouble thus avoided is the charring of the wood, which usually occurs along seams to which water has access: proper caulking prevents this. Also, any metal in the wood to which water has access corrodes and causes charring. This is prevented by using hidden screws, a hose pipe inlet, and a plain hole outlet. The hose pipe inlet obviates troublesome short circuits to earth, and the weir also provides for adjustment of water level. The double sides prevent leaking and undue bulging.

For tanks of larger dimensions iron stays may be used, but these should be carried outside the tank, an obvious but often neglected precaution.

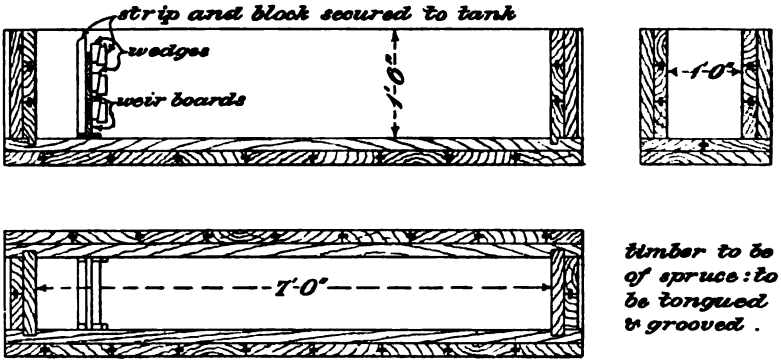


FIG. 6.—Construction of Wooden Tank for Water-load.

As this tank is for high-voltage work it is supported on insulating pedestals. These can conveniently be constructed of Doulton's glazed earthenware "acid tiles," built about 3 ft. high, with a rubber pad between each horizontal face to prevent slipping.

The water from the outlet hole is carried to a funnel or tray just above the floor level. A lead-lined saveall is provided.

The operator has a wooden platform supported on earthenware blocks, and covered by a rubber mat.

The electrodes are of iron, and are well insulated from their supports, which take the form of stout wooden cross-bars which can be slid along the tank top. The plates are clipped to busbars carried at a considerable height, and the connections are so guided as to be neat and safe. Such an arrangement can be cheaply made, and gives satisfaction up to 6,000 volts.

A low-voltage tank construction can easily be deduced from the above, but probably the area will have to be obtained by using a

number of electrodes in parallel, in which case, for variable loads, a suitably arranged switchboard is a great convenience. There are many ways of arranging the plates satisfactorily, but so much depends upon the type of testing for which they are constructed that a description of any particular arrangement will be of but little service. One point, however, should not be forgotten with iron electrodes, namely, that if they are placed less than 2 in. apart there is danger of an unsteady load, and a considerable splutter from short-circuiting by rust flakes; in fact 3 in. should be aimed at as a minimum. Sometimes, for very low-voltage work the size of the tank available is insufficient. A useful form of load can then be constructed from metal strip submerged in water.

Strip iron ½ in. wide × 19 S.W.G. supplied in 40 ft. lengths and doubled into zigzag shape will make very convenient units for low-voltage loads.

With a current density of about 25,000 amperes per square inch (the unit being immersed in moderately high resistance water) an average life of 100 hours may be expected. If, however, the cooling water is of relatively low resistance, such as canal or river water, the life is very much reduced. In actual use a unit of this form has been run at a current density in the iron winding of 52,000 amperes per square inch in canal water of a specific resistance of 440 ohms per cm.³ at 60° F., and broke down after an eight hours' run. Under these conditions the rapid wasting of the strip caused a gradually falling load. It is very convenient, when using these units, to have a small water load in parallel for fine adjustments.

Obviously the relatively short life and lack of facility of adjustment are the chief disadvantages of this form of load.

The convenience of the water resistance for absorbing a test load can be enhanced by providing a suitable apparatus for producing inductive load. Transformers and induction motors are, of course, ideal, but in their absence choking coils of cumbersome and expensive design have been constructed, usually as and when required. A cheap, reliable, and easily adjustable method of obtaining varying power factors under varying conditions is a desideratum. Such a method and construction after considerable experiment has been worked out and patented in various forms. A description of the apparatus and of the method of using it, together with an account of experiments made with it, will constitute the second portion of this paper.

Choking coils for this purpose have hitherto been constructed by placing a suitable winding on an iron core having a small and sometimes adjustable air-gap. The object of the air-gap has been to render the out-of-phase magnetising current as large as possible.

In the choking coils to be described below no air-gap at all is used, but the iron is instead worked at a flux density so high that its permeability is quite low, and the magnetising current is correspondingly large. There is, in fact, an equivalent air-gap all round the magnetic circuit.

As compared with ordinary choking coils, this construction has two distinct advantages. The flux density can be very much greater than is practicable with the older coils (three to four times). The induced voltage per turn is, therefore, correspondingly increased, and the necessary number of turns reduced. Also the magnetic reluctance is so uniformly distributed all round the magnetic circuit that the magnetic leakage is very small, and every turn of the winding is equally utilised.

The alternating magnetic energy, which corresponds to the out-of-phase current waves, is stored by reason of the magnetic state of the core itself, and not by the magnetic stress in a narrow air-gap.

The result of this design is to give an exceedingly compact choking coil for a given number of kilovolt-amperes.

Energy Loss in the Iron.—On account of the high flux density it is important, in order to avoid eddy currents, to use the thinnest laminations and to reduce hysteresis by employing the best iron. As is well known, heavy iron cores cannot be worked at 50 ∿ for long at flux densities exceeding, say, 8,000, without very special means being taken for cooling them, and at the flux densities which are being used in these new coils, such cooling is an essential condition. It may here be pointed out, however, that the object of cooling the core is not that the iron itself may be rendered cool, but that it shall not impart too much heat to the windings which surround it. The loss in the iron itself is, in fact, very substantially *reduced* by a rise of temperature of the core, partly on account of the reduced hysteresis, but much more by the increased resistance of the iron and consequent reduction of the eddy current loss, which, in cores worked at very high flux densities, is otherwise disproportionately large.

Two methods, beyond those ordinarily used for transformers, suggest themselves for working such high flux density choking coils continuously without overheating.

1. The whole coil and winding may be immersed in water kept in circulation and slowly flowing to waste.

2. The limbs of the iron core may be surrounded by coils of flat copper tube, closely fitting, in which water is continually flowing, and absorbing any heat which might otherwise reach the winding from the hot core; such coils being coupled by rubber pipes to supply and discharge, so that no current shall be induced in them.

Coils have been worked out by the authors using both these methods. In cases where the voltage permits it, there is great advantage in the first method. Not only does it provide a satisfactory means of getting rid of the heat in the core, but it allows of the use of very high flux densities in the winding. Copper for the windings may even be dispensed with altogether, and the coil may be wound with iron strip worked at current densities which would be high even for copper if not specially cooled. Such coils are in the highest degree economical to construct and prove perfectly satisfactory if the voltage of the generator to be tested does not exceed 1,000–2,000. Coils of this type have been

designed by Mr. Walshe for Messrs. Belliss & Morcom, and the authors are indebted to him for much ingenuity in designing apparatus and taking records for the purpose of this paper.

For voltages much higher than these, or where a more durable apparatus is necessary, it is preferable to use water-cooled cores of the type described above.

It is useful to give a comparison between a transformer and a choking coil wound on the same sized core and worked at the same current densities.—Consider a low-voltage 10-k.w. transformer of standard design. Its "magnetising" current, by which is meant the out-of-phase component of its no-load current of, say, 1 per cent., is such that at the peak of the waves there is a field of, say, $\mathbf{H} = 1$, giving a maximum flux density of, say, $\mathbf{B} = 5{,}500$. Now replace the primary and secondary windings by a single winding of double the carrying capacity, and increase the primary terminal pressure to four times its former amount. The single winding must now take current enough to make $\mathbf{B} = 22{,}000$, which requires, say, $\mathbf{H} = 200$, so that the current taken is two hundred times as great as the old magnetising current, and twice as great as the normal full-load current of the old transformer.

This current passes through a winding of twice the old carrying capacity. With the current doubled and the voltage quadrupled, the kilovolt-amperes of the apparatus now are eight times as great as those for which the transformer was built, or 80 kilovolt-amperes; and this with the same current densities as before.

To test a 1,000-k.w. set at 0·8 power factor requires approximately 1250 kilovolt-amperes, and 750 kilovolt-amperes of idle current, or three 250 kilovolt-amperes choking coils. With the special cooling described above, these inductive coils can be constructed on cores not exceeding in size those which would be used for three 25-k.w. transformers.

Power Factor.—Referring again to the example of a 10-k.w. transformer, the copper loss in the windings might be 3½ per cent., or 350 watts. At these high flux densities the core loss may be as much as 1,100 watts. Thus the total loss is 1,450 watts, and the power factor of the current taken is accordingly $1{\cdot}45/80 = 0{\cdot}018$. This is an

Continuous Rating with Special Cooling of the Core if Necessary	Minimum Power Factor	Phase Displacement of Current.
Kilovolt amperes.		Degrees.
0·25	0·090	84·5
0·80	0·060	86·5
2·00	0·035	88·0
10·00	0·030	88·3
40·00	0·020	88·8
120·00	0·015	89·1
340·00	0·012	89·2

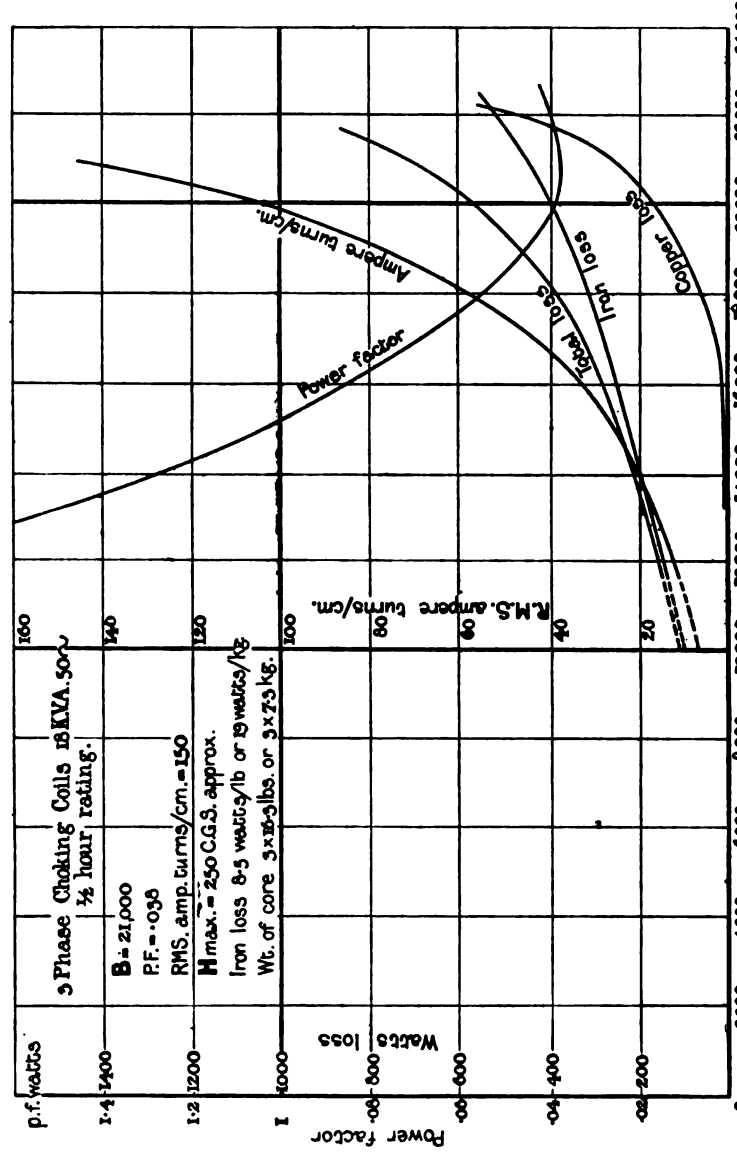


FIG. 7.—Characteristics of 3-phase 18-kilovolt-ampere Choking Coil at 50 ~.

exceedingly low power factor, and corresponds to the lowest that can be obtained with a choking coil of the ordinary construction, even when very liberally designed. It represents a lag of nearly 89°. The lower the power factor the less the energy which has to be got rid of in the inductive coils, and consequently the higher the figure at which such coils may be rated.

The minimum power factors obtainable with different sizes of these coils are found by the makers to be approximately as shown in the table on page 145.

The manner in which power factor varies with the voltage or flux density is clearly shown in the curves (Figs. 7 and 8). The data given

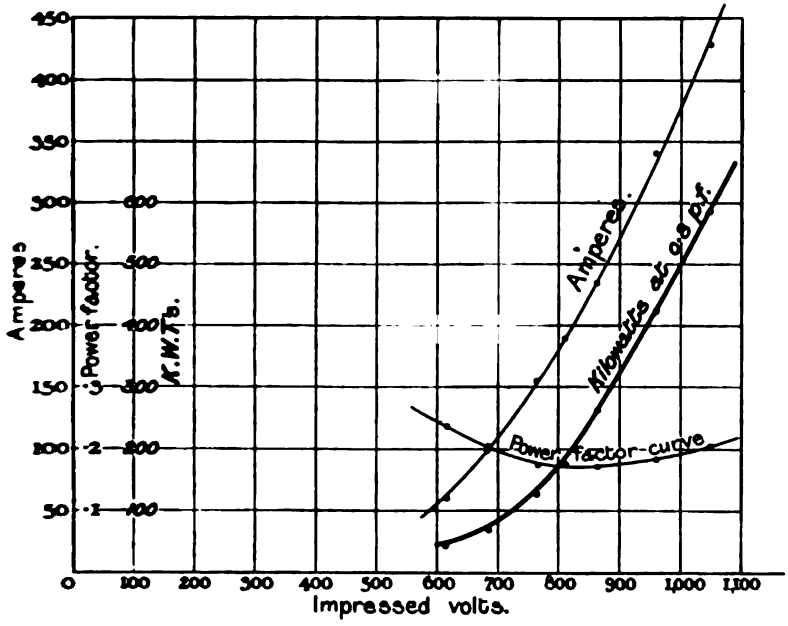


FIG 8.—Characteristics of Single-phase Choking Coil Wound with Iron Strip.

in Fig. 7 relate to the condition of working which gives the least power factor. Curves showing the various losses are also given.

Characteristic of Closed-Core Choking Coils.—The relation between impressed terminal voltage and current (r.m.s.) taken by the coils, depends upon the magnetisation curve of the iron used in the core, as well as on the wave-form of the current itself. At high flux densities a relatively small drop in voltage reduces the current almost to nothing. It is characteristic, therefore, of these choking coils, that while they work well over a wide range of current, yet their range of voltage is small.

Regulation of Voltage and Current.—It is not practicable to have special inductive loads made for every voltage and current of the

machines which may have to be tested. It is therefore of the greatest importance to provide means whereby the voltage as well as the current of an inductive load may be regulated while the power factor is maintained at a specified value of, say, 0·8.

The most satisfactory method of arranging for such regulation is by means of water resistance arranged in such a manner that the inductive coil current is shunted by an in-phase component of current in a water load, while, at the same time, resistance may be put in series with the choking coil (see Fig. 9).

By shifting the plate B towards A or C, the double adjustment may be conveniently effected at one time. Adjustment is also obtained by raising or lowering one or more of the plates. The inductive coil may be either immersed in the tank, or may be in a separate place according to the method used.

Further variations of voltage and current may be obtained by the well-known methods of paralleling the coils, or changing from star to

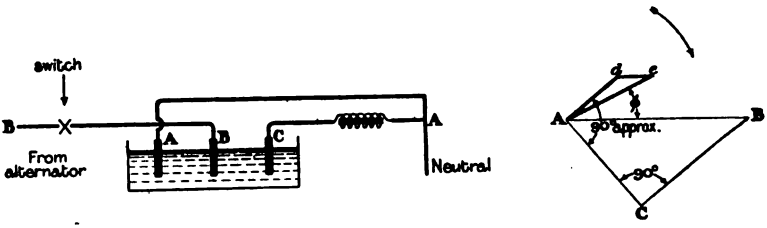


FIG. 9. - Combined Water Load and Inductive Load.

A B = Total voltage to neutral.
A C = Voltage across choking coil.
B C = Voltage across series resistance.
A *d* = Current in choking coil and series resistance.
d c = Current in shunt resistance.
A *c* = Total current.

mesh connection or both, used always in conjunction with the above combination of water loads (Fig. 10).

Since the change from star to mesh coupling reduces the voltage for which the inductive set is suitable and increases the current by $\sqrt{3}$, it is convenient to make the next step down in voltage correspond to the paralleling of three equal sections of the winding, since this will again give a step $= \sqrt{3}$. The next step, again, would then be by changing from star to mesh, the coils remaining still in parallel.

In this way an extreme range of voltage of as much as 9 : 1 may be obtained with a 3-phase set, each of whose windings is subdivided into three parts only, while throughout this range the set can be worked, if required, at constant kilovolt-amperes and core flux density. For testing at reduced loads the correspondingly smaller kilovolt-amperes are obtained by working the cores slightly at lower flux density.

For economy in design it is best to use choking coils wound for the lowest voltage which will satisfy the purpose for which the coils are

required. If they are wanted for testing 3-phase generators at a moderate power factor, it will be found that the necessary coil-voltage is not more than one-third to one-half of the terminal voltage of the machine under test.

For example, let it be required (see Fig. 11) to test a generator of 1,000 k.w. at 6,000 volts and 50 ∿; the test to be carried out at 0·75 power factor. Using Y-connections, this means in each branch a voltage of 3,460 and a current of 128 amperes, being the resultant of an in-phase current of 96 amperes and an out-of-phase current of 84·7 amperes. Each branch of the circuit requires therefore a choking coil designed for 84·7 amperes and 3,460 volts, shunted by a water resistance taking 96 amperes at the same voltage. No water resistance whatever would be used in series with the coils.

It is possible, however, to obtain the same result using choking coils wound for lower voltage and correspondingly higher current. The

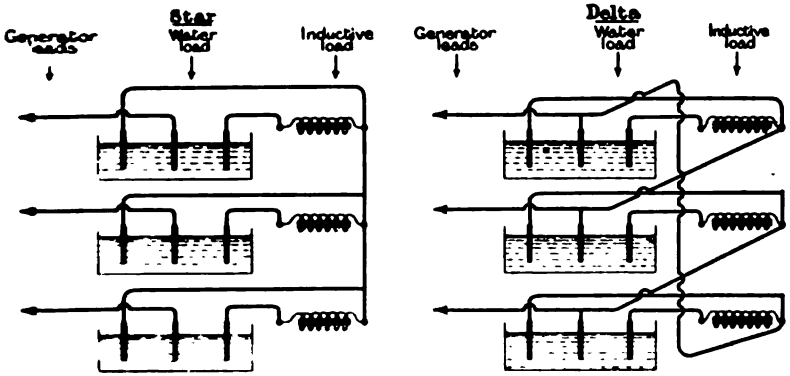


FIG. 10.—Connections for 3-phase Working.

coils can each be wound for the full current, 128 amperes, and resistance can be arranged in series only with the coils. If the coils are so designed that, when taking this current, the voltage across each coil is 2,290 volts, while the drop across each water resistance in series with a coil is 2,600, then, since these two voltages are practically in quadrature, the full phase-voltage of 3,460 volts will be maintained as before and the current will be 128 amperes, at 0·75 power factor also as before.

Thus, to carry out a 0·75 power-factor test on a 1,000-k.w. 6,000-volt generator requires three coils each for 128 amperes at 2,290 volts only; while the combined kilovolt-amperes of the coils is 3 × 128 × 2,290, or 880 kilovolt-amperes as compared with the 1,333 kilovolt-amperes of the generator. Similarly, if the test had been required at 0·85 power factor the coil-voltage would have been 1,820 volts, and the combined kilovolt-amperes of the coils 620, the generator kilovolt-amperes being now 1,130.

Generally, if—

E_g = terminal volts of 3-phase generator,
W = output in k.w.,
and Cos ϕ = required power factor during test;

then the three choking coils needed should be wound each for a current of $I = \frac{W}{(\sqrt{3} . E_g . \cos\phi)}$, and a voltage of $E_c = \frac{E_g . \sin\phi}{\sqrt{3}}$. The

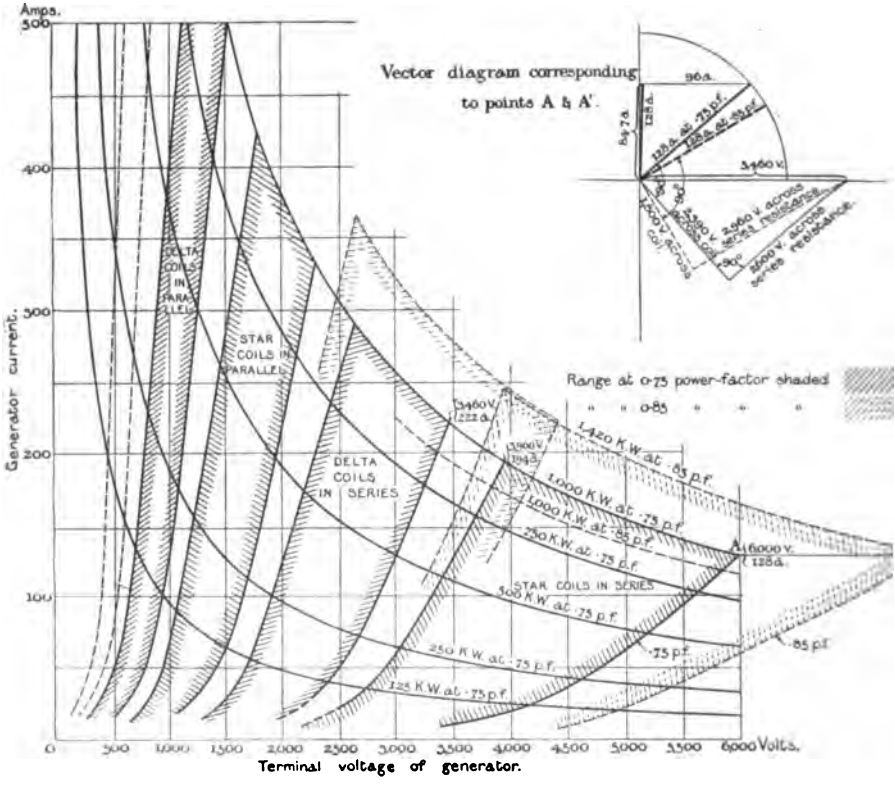


FIG. 11.—Range of Voltage and Current with given 3-phase Choking Coils.

maximum combined kilovolt-amperes of the three coils is, therefore, = W tan ϕ.

It will be plain from the above that the combination of inductive coils and water resistances described in the paper is capable of dealing with a given number of kilowatts at a specified power factor over a range of voltage extending from $E_g \sqrt{3}$ down to sin ϕ times this amount, where cos ϕ is the power factor. The range of current is correspondingly as sin ϕ : 1.

Throughout this range both voltage and current of each choking coil are those for which the coils have been assumed to have been designed. When the coil-voltage is reduced the current will fall off rapidly after the manner shown in Figs. 7 and 8. By using similar arguments to those given already, it is seen that a combined inductive and water-load as described can deal with a range of voltage and current, and also with a range of power as well, at a given power factor. Such a range is shown by the shaded area on the right-hand side of the figure (Fig. 11) worked out for 0·75 power factor and 1,000 k.w. or less.

To extend the range of the set the method described on page 148 is used. The sections of the combined load are coupled in mesh or delta connection. In this way the current capacity is increased as $1 : \sqrt{3}$, while the voltage limits are correspondingly reduced. On referring again to Fig. 11, it will be noticed that this covers another large range of voltage, current, and power which will overlap the former range only when $\sin \phi$ is equal to or less than $1/\sqrt{3}$, or 0·578, which means that the power factor of the test must not be less than 0·816. Above this power factor the ranges covered overlap ; below it there are certain currents and voltages which cannot be dealt with.

To deal with yet lower voltages and higher currents the windings on the coil are each divided into three sections. These, when paralleled and star-coupled, give a set of volt-ranges one-third of those first available, and consequently reduced as $\sqrt{3} : 1$ from the second arrangement in which the apparatus was delta-connected and all the windings on each core were in series.

Lower voltages still can, of course, be obtained by delta-coupling the third arrangement ; and, if advisable, by further subdivision of the coils into nine sections each.

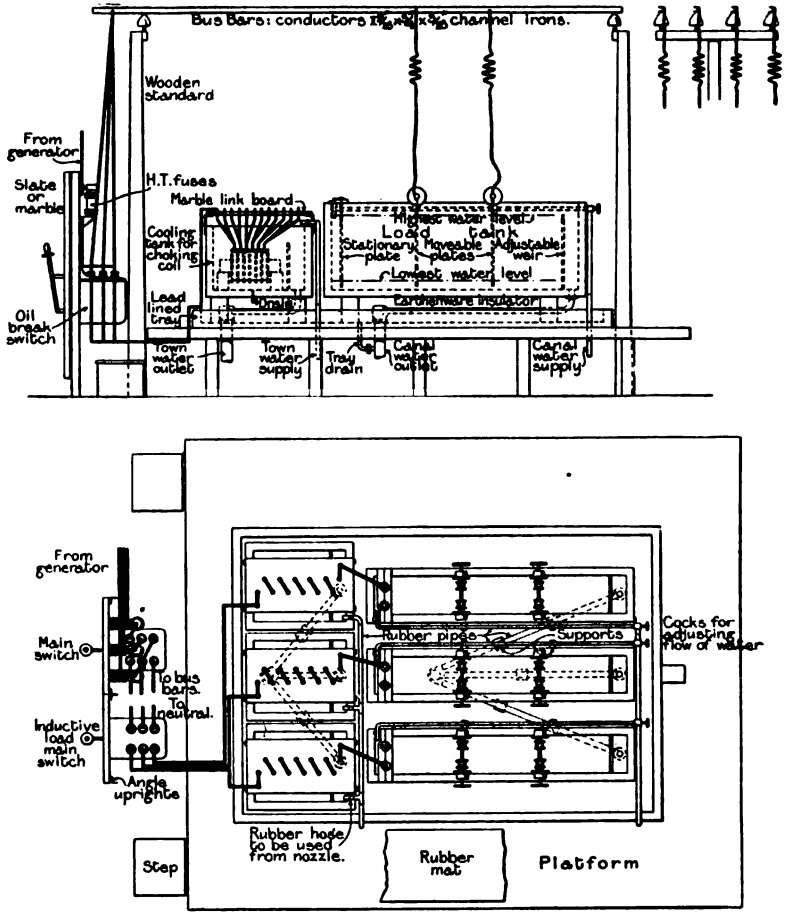
In each of the arrangements the range of power which can be dealt with at a given power factor is the same—namely, 1,000 k.w. and less for tests at 0·75 power factor, and from 1,420 k.w. and less for tests at 0·85 power factor.

The combination of coils and water-loads described here is thus of a very flexible nature and well suited to deal with the variety of generators which may have to be tested commercially.

The kilovolt-amperes of an inductive load being fixed, the winding must be so chosen that the following conditions are satisfied : (*a*) It must carry the required current without undue heating continuously, or, in special cases, for a given short period ; (*b*) its number of turns must be such that, when carrying this current, a back E.M.F. equal to the required coil-terminal voltage is obtained ; and (*c*) there must at the same time be enough ampere-turns operating on the coil's magnetic circuit that the requisite high flux density is obtained. If the coil is above a very small size, and not required for short-time rating only, the core must be cooled.

The use of these coils worked at such high flux densities gives rise to a current-wave whose peak is about 10 per cent. higher than that of

an equivalent sine-wave of current. That is, in calculating the ampere-turns available for producing the maximum of flux density the r.m.s. ampere-turns must be multiplied by about 1·56; so that the value of **H** is about 1·96 × the r.m.s. ampere-turns. The approximate field is



FIGS. 12 AND 13.—Suggested Design for Artificial Load Inductive and Non-Inductive, Suitable for 1,000 k.w. at 1,000 to 6,000 volts. Also at 500 volts with Heavier Switch Gear and Leads and with Extra Plates for Water Load.

therefore roughly obtained by doubling the r.m.s. ampere-turns. The distortion of wave-form is, however, not very great owing to the very high flux density, and therefore uniformly low permeability which occurs.

Approximate data relating to Sankey's Lohys and Stalloy irons at these high flux densities, based partly on the authors' experiments, are given below :—

B	H		Loss per lb. at 50 Periods.	
Lines per sq. cm.	Lohys. C.G.S. Units.	Stalloy. C.G.S. Units.	Lohys. Watts.	Stalloy. Watts.
18,000	100	132	5	4·0
20,000	220	275	8	7·5
22,000	360	440	11	10·0
24,000	500	600	14	12·5

The most suitable design of choking coil is in many cases that giving the *least power factor*. This factor is the ratio of copper and iron

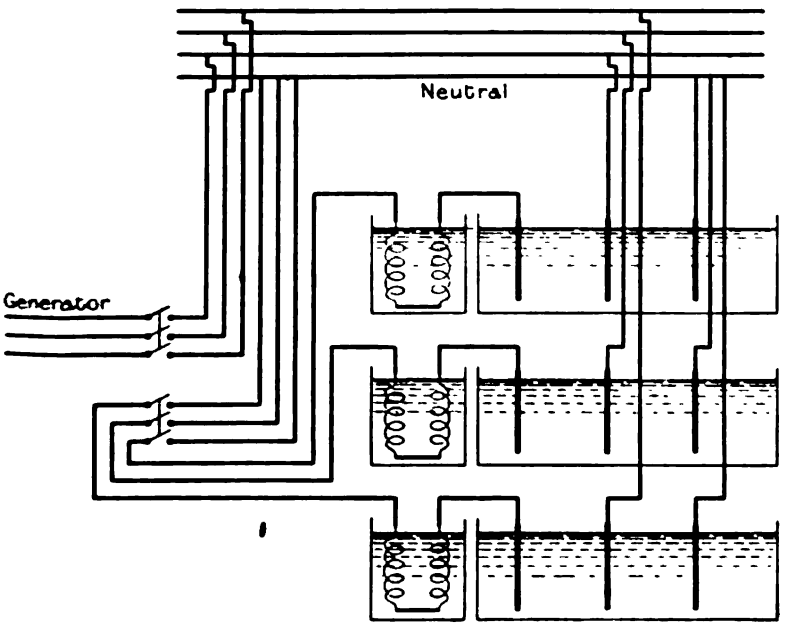


FIG. 14.—Diagram of Connections on Figs. 12 and 13.

losses to the total kilovolt-amperes of the choking coil. The losses depend on the square of the current and on some similar function of a not widely varying flux density, while the kilovolt-amperes are pro-

portional to current and flux density. Thus there will be a point at which the power factor is a minimum which occurs at a higher flux density the larger the coil. This is illustrated in the curves already given in Figs. 7 and 8.

It is difficult to generalise as to the best method of combining the details, but the authors append a suggestion for a working plant on lines which have been found very satisfactory in practice over a large range of conditions (see Figs. 12 and 13). The diagram of connections for this arrangement is given in Fig. 14. The inductive coils here shown are cooled by immersion in suitable tanks in which water is circulated, as also in the main load tanks by a system of pipes clearly indicated.

Discussion in Birmingham.

Mr. Kemp.

Mr. J. P. Kemp: I have had considerable experience in the use of water load for high-voltage tests, and have found it to be the only suitable form of load where large amounts of energy have to be

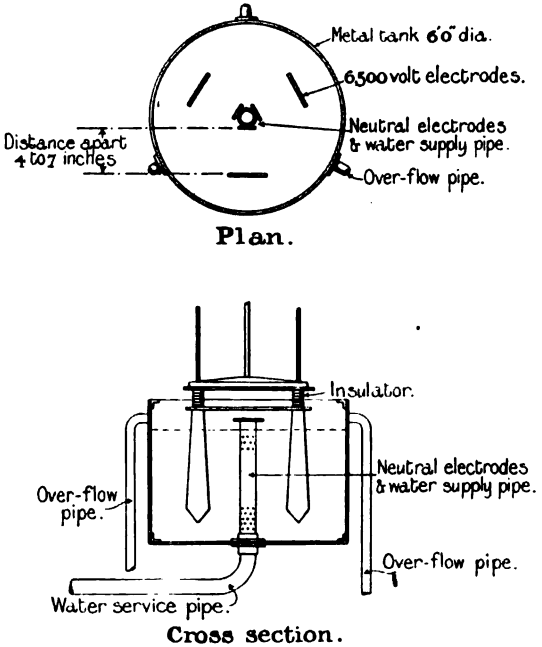


Fig. E.—Type of A.C. Test Tank in use at Manchester and Birmingham.

dissipated. With wooden tanks, however, I have experienced that they have caught fire and the water leaked out.

In Manchester, at the Stuart Street station, I have used for 3-phase 6,500-volt work, a circular iron tank 6 ft. in diameter and 4 ft. deep, an

illustration of which is shown in Fig. E. The outer electrodes are symmetrically spaced at 120°, being about 7 in. away from the neutral element, and the water, which is introduced in the centre at the bottom of the tank, flows away over a weir at the top. With this particular tank 4,000 k.w. has been successfully absorbed for over six hours. The outer body of the tank also forms part of the neutral element, and as this is substantially earthed, there is no possible danger from shock. With wooden tanks, however, there is considerable risk of men receiving a shock from the body of the tank or even from the water. In these tests I used town water; under these conditions it was possible to vary the load from 40 to 4,000, simply by varying the immersed area of the electrodes, the amount of water being constant. As a precaution against failure of the water supply and the consequent increase of load I used a drain pipe at the bottom of the tank; the amount of load on the tank was, however, under perfect control, and could be readily adjusted by means of a small motor operated from the switchboard. It would not be possible to use canal water in small metal tanks for 6,000-volt tests. Mr. Kemp.

In giving the specific resistance of condensed or canal water it is more convenient to give this as so much per cubic foot and not per cubic centimetre as in the paper. Even better, it might be given as the resistance between opposing plates 1 ft. square and 1 ft. apart, which is not quite the same thing as the resistance per cubic foot.

As a permanent adjunct to a central station, a suitable water load is very desirable, for it enables one to perform various adjustments to valves, governors, etc., as required; it is certainly expensive, but there is no question about its advantage and superiority over the temporary arrangements frequently provided for official tests.

The main point of interest in connection with the paper is the very ingenious method devised for obtaining loads of varied power factor, and I understand this to be the only simple and satisfactory apparatus which has so far been adopted. Its use will therefore be of undoubted advantage to those engineers who desire to test their alternators on inductive loads, as up to the present, although a variety of inductive-load tests have been called for in specifications, I do not know of any case in which they have actually been carried out.

Mr. J. M. WALSHE: The best design of tank is one which will allow of the greatest range of loads, and with a circular metal tank and Birmingham canal water it would be quite impossible to get small loads at high voltages. With low-resistance water it is necessary to have a long, narrow tank. Three tanks, each 6 ft. long, 1 ft. deep, and 6 in. wide have been found quite large enough for 950 k.w. at 7,500 volts, and the load could be reduced to 40 k.w. at the same voltage. This range would not be possible with metal tanks using canal water. A point in connection with the use of small tanks is that the water supply must be reliable and regular, as owing to the decrease of resistance with the rise of temperature of the water, there would be danger of a heavy overload if the supply were to fail. With tanks of small Mr. Walshe.

Mr. Walshe. capacity the rise of temperature is very rapid. An open drain should be fitted under the weir, so that in case of a failure of the water supply the level of water in the tank would fall and the resistance would remain about constant.

Mr. Chattock. Mr. R. A. CHATTOCK: The authors state on page 141 that the voltage drop per foot of water should not exceed 600. Does this apply to high- or low-tension current? If the latter, I think it a very low figure. I consider that the limit of current density of 1 ampere per square inch of plate is too high. It is not clear whether the figure refers to plates in running or in stationary water, but certainly in stationary water boiling would occur in a very short time with probably ½ an ampere per square inch. I once carried out some tests in which I used two plates placed in a canal. The conditions were 100-k.w. load at 1,000-volt single-phase alternating current; the electrodes were 15 ft. apart, the immersed area of each being 10 sq. ft. One could feel the effect of the electric current in the water at least 50 ft. away, and fish were killed within a radius of 20 ft. As a danger signal whilst the test was going on, a small raft was moored between the electrodes, from which two iron plates were suspended in the water 18 in. apart; a 100-volt lamp was connected to these plates, and the drop in pressure was sufficient to light this up. I have tried a single-phase test with a metal tank as one pole and a rod in the centre of the tank as the other, and the result was practically a short circuit. By using the same tank and two rods, one for each pole, quite satisfactory results were obtained. I have had trouble with wooden tanks owing to deterioration of the wood allowing water to leak, which caused charring on the outside; I have also known the wood to catch fire if this was allowed to go on.

Mr. Forrest. Mr. F. FORREST: The amount mentioned on page 138 of 5 gallons of cooling water per kilowatt-hour for 70° rise is practically that obtained by calculation, using Joule's equivalent. On page 142 the authors, in describing a 6,000-volt tank, say that the position of the electrodes can be adjusted by sliding the supports along the top of the tank. Personally I should not like to do the sliding. Some mechanical means of adjustment is necessary such as a right- and left-hand screw or a pulley arrangement.

Mr. Coales. Mr. J. D. COALES: I desire to call attention to the peak in the wave-form of the current in a choking coil worked at high flux density, and am able to show the no-load current wave-form of two 7½-k.w. transformers, the primaries of which were connected in parallel to 208-volt mains instead of being supplied at their rated pressure of 116 volts, The frequency was 50 ∿ per second, the effective current 9·3 amperes, the maximum value as shown by an oscillogram being about 18·7 amperes, and the maximum flux density about 10,600 lines per square centimetre. The duration of a peak is confined to a comparatively small portion of the cycle with its middle point roughly coincident with the instant of zero pressure, and I suggest that, when an alternator is tested on such an inductive load, the "drop" might be exaggerated unfairly, owing to the concentration of the demagnetising reaction into

Mr. Coales.

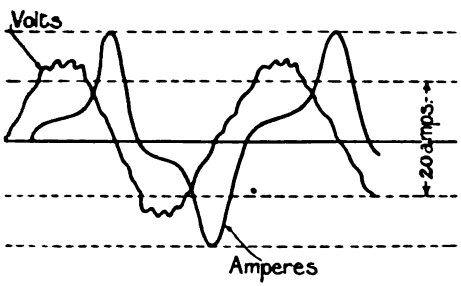


FIG. F.

$$\text{Mean } \cos\phi = \frac{610}{93 \times 208} = \frac{610}{1{,}940} = 0{\cdot}315.$$

93 amperes effective ∿ = 50.
208 volts.
610 watts.
Maximum value of amperes 18·7 amperes.
B maximum = 10,000 approximate taking Form factor = 1.11.

a small part of the cycle where it is most effective. Have the authors found this to be the case?

Dr. W. E. SUMPNER: The paper is divided into two distinct parts, a practical portion dealing with water loads and tank construction, and a more theoretical portion bringing forward a new feature in connection with the design and construction of a load suitable for taking current at a given power factor. The novelty consists in using a choking coil with a closed iron magnetic circuit, and working it at very high flux densities. This latter feature is particularly interesting. Mr. Coales has drawn attention to a fact I pointed out many years ago —that the current wave in a transformer having a closed magnetic circuit consists of a shoulder and a peak. At very high flux densities the peak will certainly be increased, while the shoulder will be less pronounced. This will result in a zigzag wave of current very like a series of triangles. A sine wave is approximately a triangle with the peak rounded off, so that the resulting wave would essentially differ only very slightly from a sine curve. The use of these choking coils will thus have no unusual effect on the alternator. It is not an easy problem to test a generator at a given power factor, especially for 3-phase circuits. The usual method is to make a trial choking coil without iron, and to alter and reconstruct it until a more or less suitable load is obtained. In the method used by the authors several coils are employed, so as to secure a wide range of voltage, and the power factor is adjusted by combining the choking coil with water loads in series and in parallel. This makes the arrangement very flexible, and it should prove of great practical value. It seems to me to be the best solution of the problem of obtaining an alternating-current load of adjustable power factor.

Dr. Sumpner.

Mr. N. B. ROSHER: I should like to ask if the authors have fully considered the use of wire resistances. I had experience with these

Mr. Rosher

Mr. Rosher. some years ago and found them to work well. They were mounted on light angle iron frames in units of convenient size, for connecting up to test-room terminal boards. One advantage of such units is that they can be made quite portable, and the practice was to despatch them from the works for the testing of generators after final erection.

This obviates the necessity of rigging up temporary water resistances, which I have found from practical experience is frequently a difficult and messy business.

Mr. Gott. Mr. A. E. GOTT : I am particularly interested in the portion of the paper dealing with water resistances. As an illustration of the high resistance of pure country water, I may mention an experiment made, previous to a dissipation test, on an ordinary oil barrel filled with water. Lead plates were used each with 2 sq. ft. immersion. When brought to within only ¾ in. of each other, 100 volts only gave 2 to 3 amperes. The addition of two or three ounces of acid enabled me to dissipate 60 H.P. with the plates at a safer distance apart. The capacity of a barrel is 20 H.P. for 1 hour before boiling. I never saw a large water resistance without thinking that it was by no means satisfactory. The troubles of electrolytic action, corrosion, bad insulation, and shocks are inseparable from its use, and I consider it highly dangerous on extra high-pressure work. In my opinion insulated water tanks will not be tolerated as permanent plant under the new Home Office Regulations, a point which seems to have been overlooked in the paper, and I would advocate the use of wire coils immersed in oil and surrounded by a water circulation. It is possible in this way to dissipate continuously 10 k.w. with a unit which can be carried in one's pocket.

Dr. Kapp. Dr. GISBERT KAPP : Referring to the question of insulation, I think it is not sufficient to earth the tank. It is not possible to get a better earth than canal water, and yet it is possible to get a shock from the water. The tank itself should be earthed, but surrounded by a platform supported on insulators and covered with a rubber mat. We have heard about wooden tanks which have given trouble owing to fire and metal tanks which have corroded. I should like to ask whether the authors have had any experience with earthenware, which appears to possess the advantages of both with the drawbacks of neither. I have used earthenware tanks for small loads, and have found them to work very well. I should also like to ask the authors if they have observed the actual power factor of a resistance, consisting of iron plates in water. I believe that this is not quite unity, but that the water load takes a leading current. Electrolysis is continually going on, and produces a film of gas on the plates, thus forming a condenser. This effect, combined with the ohmic resistance, results in the power factor being not quite unity.

Mr. Davis. Mr. OSWALD T. DAVIS : It will be seen from the authors' table of specific resistances that a successful water resistance requires a water with a large percentage of mineral matter in solution. As they point out, hot well water has a very high specific resistance at 60° F., and is

therefore unsuitable. Nevertheless, I have used the hot well for a water resistance on one occasion for a 150-k.w. 230-volt machine, sufficient current being obtained with a fairly small battery of resistance plates by reason of the high temperature of the water (about 150° F.). As a general rule, the circulating water discharge from a surface condensing plant is suitable for use in an artificial load. Mr. Davis.

For a permanent resistance it is convenient to have one large tank, and I am distinctly in favour of a brick-built, cement-lined tank. For a low-voltage resistance the plates (which may be of ½-in. sheet iron for

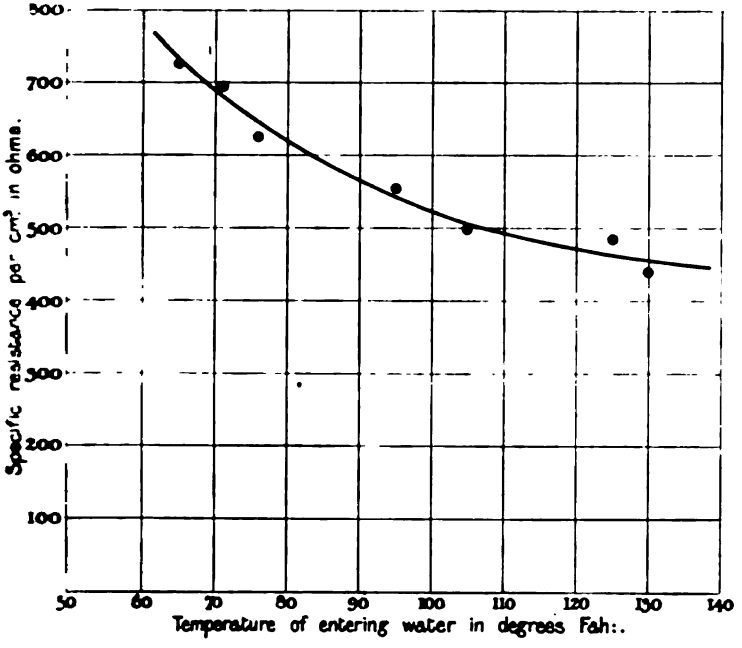


FIG. G.

lightness) should be fixed in frames a certain distance apart, and the load controlled by raising or dropping the whole frame into the water. This arrangement reduces the necessary size of the containing tank. It is good practice to have a light fuse in series with each individual positive plate, and the plates may be grouped, the groups being controlled by switches. The load may then be prepared by lowering the resistance frame into the water, switching on a certain number of groups of plates, and finally securing fine adjustment by further raising or lowering, or preferably by manipulating a weir on the outlet.

Using water with a resistance-temperature curve given in Fig. G, I

Mr. Davis. have found the following to be convenient distances from positive to negative plates :—

100	volts	...	...	...	...	2 in.
200–300	„	...	...	...	...	3 „
400–600	„	...	...	...	...	5 „
1,000	„	...	...	...	...	7 „

which values, it will be seen, give much lower values for the current density than the limit of 1 ampere per square inch given by the authors. With the water the positive plates get covered in time with a rust scale. This, however, can be easily scraped off or released by tapping the plates with a hammer. When corroded to a certain extent it is convenient to alter the connections so that the negative plates become positive, and *vice versâ*, thus ensuring an even life for the whole set of plates. Iron-wire resistances immersed in water are not permanent enough for standard use, but are useful in exceptional cases. They are best arranged in a box, and should be well swept with water flowing through. If run at a density of about 10,000 amperes per square inch, their life is fairly long. For extra high voltage work it is necessary to insulate well the source of the entering water, and I have found a small erection resembling a cooling tower useful for breaking up the water into drops.

As regards the use of choking coils, it must be remembered that ordinary commercial work only calls for power factors of 0·75 and above, and this point should be considered when designing chokers. Generally speaking, the use of choking coils on machines under test is limited to determination of the increase of excitation or voltage drop. For this reason the period during which they are in use can be kept small, and artificial cooling may be dispensed with. On the other hand, most engineers desire to see their plant tested under a load as closely as possible approximating to that which they will be called upon to take up in everyday practice, and therefore it is best to design the chokers to enable their use on long temperature and steam consumption runs. A point often lost sight of by engineers in charge of the latter class of tests is the reduced efficiency and consequent increased steam consumption of machines when under inductive load. The extra losses (that is, increased armature and excitation copper losses) often amount to 2 per cent. of the output, and hence will make an appreciable difference to the steam consumption.

The authors have not touched on the question of capacity effects due to the use of water resistances on alternating-current machines. Some years ago I investigated this subject rather closely, and came to the conclusion that the power factor in ordinary cases always approaches unity very closely (careful measurements giving actual values of 0·985 to 0·998). The lead of the current on the voltage is indecipherable on an oscillographic record. Quite recently, however, when testing a large generator on a water load with very small electrodes, a curious momentary rise in terminal voltage was noticed when full

load was suddenly switched on, the switching being performed by dropping the electrodes into the water. I hope to investigate the phenomenon with an oscillograph shortly. Mr. Davis.

Mr. R. K. KEER (*communicated*): The following particulars of a liquid resistance, with the design of which I have been concerned, may be of interest. The resistance is placed in one of the electrical laboratories of the Municipal School of Technology, Manchester. It is intended primarily to form a load for a 25-H.P. 500-volt traction motor when driven as a generator by another similar machine. Being of a permanent nature, the tank was built of glazed Staffordshire blue bricks, in cement, the walls being 9½ in. thick. A layer of mastic asphalt, ¼ in. thick, was put between the two thicknesses to make it watertight. The internal dimensions of the tank are 6 ft. 9 in. by 2 ft. 6 in. by 2 ft. It is placed in a pit, the bottom of which is 4 ft. 4 in. below the level of the floor. This pit is partly roofed over with steel girders, to which machines can be bolted for testing. The space between the girders is fitted with trap-doors. The electrolyte used is a 2 per cent. solution of aluminium sulphate, the electrodes being lead plates. This makes a very clean arrangement as practically no sediment or fumes are formed. The arrangement of the plates is as follows: At one end of the tank are four fixed plates, each 12 in. square and ⅛ in. thick. They are placed parallel to the length of the tank and at a distance of 7½ in. from each other. The movable electrode consists of three plates, each 1 sq. ft. in area, but V-shaped at the bottom. These are fixed to a simple carriage, fitted with wheels, which runs on two lengths of gas pipe placed on an incline, sloping down towards the fixed plates. When the movable plates are at this end they are completely immersed and fit in between the other plates. This gives an area of 6 sq. ft. the distance between the plates being 3¾ in. As the plates are moved away they rise up the incline, and thus out of the liquid at the same time. The plates are moved from above by means of a hand wheel actuating a winch through bevel gearing. A brake is provided to prevent the plates running back. The whole arrangement is well coated with anti-sulphuric paint. Connections are made to the movable plates by means of flexible cables. Mr. Keer.

This arrangement of the plates gives a very large variation of resistance. Thus with a 1 per cent. solution, which was tried at first, the resistance could be varied from about 50 ohms with the plates just touching the liquid to about 0·75 ohm, when they were completely immersed. The lowest resistance required was less than this, so the amount of aluminium sulphate was doubled, bringing the resistance down to about 0·5 ohm. The resistance varies considerably with current density as the following figures show. With the 2 per cent. solution and with the plates completely immersed, the resistance with 10 amperes was 0·8 ohm, with 20 amperes 0·65 ohm, gradually becoming less until with 100 amperes it was only 0·48 ohm. The "resistance" measured includes, of course, a certain amount of back E.M.F., which is constant and therefore most apparent with the small currents, and

Mr. Keer. helps to account for the variations obtained. Apart from this the variation is not due entirely to temperature rise, for the readings were taken quickly before there was time for much rise in temperature to occur. To test the temperature rise of the tank it was loaded with 25 k.w. (50 amperes, 500 volts) for one hour. The temperature rise at the end of the hour was 27½° C. (from 14½° to 42°). While at this temperature the resistance with plates completely immersed and with 100 amperes was 0·335 ohm as compared with 0·48 ohm when nearly cold.

The movable plates are connected to three separate terminals, so that higher resistances can be obtained by using only one plate. By using the middle plate as the common connection the tank can be used for a balanced 2-phase load, but will not, of course, give a balanced 3-phase load.

Mr. Digby. Mr. W. POLLARD DIGBY (*communicated*): My remarks are confined to the value of conductivity determinations of, say, hot well water from a surface condensing plant. The first question in any such study is as to the value to be allowed for the specific resistance of distilled water. The table at the top of page 138 gives 600,000 ohms. But even with ordinary care, with a Liebig condenser in the laboratory, 300,000 to 400,000 ohms is a fair figure. It is only with special care that 600,000 to 750,000 ohms is attainable. With extraordinary precautions Kohlrausch has, I believe, produced distilled water with a specific resistance of 1,100,000 ohms per cubic centimetre at 18° C. The absorption of impurities from the vessels in which the water is condensed, and the absorption of impurities from the atmosphere reduce the value to a lower figure. Indeed, if 50 cubic centimetres of distilled water is shaken up for 30 seconds in a thoroughly clean stopped 100-c.c. flask, the resistance will be found to have fallen about 40 to 50 per cent. As regards impurities the hyperbolic curve given in Fig. 1, with its abrupt fall, is typical of all substances soluble in water. The addition to a distilled water having a value of 300,000 ohms of only one part per million of sodium chloride will reduce that resistance to about one-half.

For any tests the central station engineer may require to carry out, I think that 300,000 ohms may be taken as a standard value for fairly good distilled water. I have, indeed, had samples of water from surface condensers of this value. Given such a liquid (which cannot usually be obtained from a pharmaceutical chemist) curves such as that given in Fig. 1 may be obtained for any variety of circulating water passing through a condenser. Then if a hot well water gives a relatively low resistance owing to the presence of impurities it is obvious that these must be due, as the authors point out, either to a leaking surface condenser or to boiler priming. It is, moreover, possible to determine which of these causes is accountable. If during times of light load, when the condenser is dealing with small quantities of steam, the resistance is lower than when larger quantities of steam are dealt with, it is obvious that the condenser is leaking. But if with an increasing load the resistance of the hot well water falls, priming is the obvious

cause. The preparation, then, of a comparative curve giving the relation between resistance and varying proportions of the water actually in the boiler in standard distilled water will enable the amount of priming to be determined. Mr. Digby.

As regards the allowance to be made for temperature, I do not think that even for practical purposes it suffices to accept a percentage reduction of the resistance over a range of 70° F. from 60° F. I find that the percentage fall of resistance from that of any initial value is much greater between 20° C. and 40° C. than, say, between 40° C. and 60° C., and that in any case the percentage amount of the fall varies with the initial purity of the liquid.

Mr. R. K. Morcom (*in reply*): One of the criticisms on the water resistance has been the risk of receiving a shock from the water. I have never experienced any trouble of this kind. The necessary precautions are quite simple. There are objections to using the hot testing water in boilers. Ordinary canal water will require to be softened before it can be used in this way, and by the time it has passed through the water softeners it will have lost a great deal of heat. If the water were softened previously it would not be so suitable for testing, and any waste would be expensive on account of the chemicals used. I have carefully considered the question of utilising the power usually wasted in the test-room. It seems to be a chance of making the customer pay for the works power supply. But there are many difficulties in the way. Tests are carried out, using all sorts of pressures and currents, and at odd times. There will be considerable expense involved in the upkeep of the special plant. The system, and particularly the connections, will be most complicated to work out and to use. It would necessitate the spending of a large sum of money, and on the very best showing I have found that it would only be possible to make an inadequate percentage on the capital expenditure. Mr. Chattock said that he had trouble owing to the liability of wooden tanks to fire. Just before he had expressed the opinion that a drop of 600 volts per foot was not so much as might be employed. In my experience it is only by using a moderate drop per foot of water that it is possible to avoid charring the wood of the tank. The objection to the porcelain tanks of which Dr. Kapp has spoken is mainly that of expense. Wooden tanks have the advantage of being cheap. For instance, on the site a good temporary tank can be made out of a good packing case by simply caulking up the joints. Dr. Kapp has also suggested that a water resistance acts like a capacity. In our tests we have noticed this, as we found it necessary to use a small amount of induction in conjunction with the water load in order to get unity power factor. But I have not attached much importance to it, as the accuracy of the readings has been questioned. I do not believe that the factory inspectors will take exception to the insulated tank. They really have a very good earth in the overflow water flowing into the canal. Mr. Morcom.

Dr. D. K. Morris (*in reply*): I have to express our thanks to the members for their interest in the paper. Mr. Coales has drawn attention Dr. Morris.

Dr. Morris. to the wave-form of the current taken from the alternator by a choking coil of a new type, and has suggested that this is of an unusual shape. Dr. Sumpner has explained how this does not mean a wave differing materially from a sine wave. It is of great importance that the inductive load shall not produce a different kind of load from that occurring in practice. Considering that only 3 or 4 per cent. of the current wave is sufficient to bring the flux over the knee of the saturation curve, it will be seen that practically the whole of the current wave corresponds to the region of low permeability where, as is well known, the variations of permeability are not great. Thus, except for small initial delay, the current wave is not far from being such that its rate of change is a copy of the volt wave, and the reactions in the generator for which the test is being carried out are therefore entirely normal. A slight distortion of wave-shape is, however, quite proper in such tests, for this will occur in practice when a load of bad power factor arises.

Communicated : The construction shown by Mr. Kemp in his figure is interesting. There does not, however, appear to be any need for the central construction, as the metal tank all round serves as a more effective neutral than the central portion. Mr. Kemp asks for the specific resistance in terms of a foot cube. Although it is not generally an accepted standard, yet it is certainly useful, and we have added this to the figures given on page 138. We think that the further figure for which he asks—namely, the resistance between square foot plates in a tank—is quite useless, as it neglects the great influence of the width of the tank and the distance of the plates from the walls as pointed out in the paper. Mr. Kemp further points out the importance of artificial load as an adjunct to the plant in a station. He states it to be expensive. This is just why we advocate wooden tanks in our paper. That such an arrangement is by no means of a temporary character is shown by the fact that wooden tanks made several years ago have been in almost daily use on Messrs. Belliss and Morcom's test plate for three years, and are still doing good work. In his further remarks Mr. Kemp might even have said that it was impossible to use canal water in metal tanks at all, except for enormous loads, if the voltage were anything but low. His experience of reducing the load to 40 k.w. by reducing the immersed area of electrodes is quite contrary to our experience. The water area being so large, the small local increase of resistance by withdrawing the plates should not greatly influence the total resistance.

Mr. Chattock, in his remarks, gave figures for the Victoria Street water (New River), which appear to work out at a specific resistance of about 250 ohms per centimetre cube. The experience with metal tanks is interesting, as the resistance with two rods will certainly not be double that with one rod ; and, as he calls it practically a short circuit in the one case, it could not be far removed from a short circuit in the other. The deterioration of wooden tanks was generally due to imperfect construction, the proper method of making these being given in the paper.

The personal danger anticipated by Mr. Forrest from adjusting a

high-tension load is small if due precaution is taken, but, of course, the greatest care must be observed and only authorised persons should be allowed to have access to the load. Dr. Morris.

Mr. Rosher evidently wishes to return to wire resistances. We are not inclined to share these views.

The question of earthing or not earthing the tank is most important. It has been referred to by several speakers. We have found that one earth through the water outlet must exist, and it is better not otherwise to earth the tank. And if the floor of the platform is efficiently insulated, as when covered by a good rubber mat, and if it is so placed as to prevent access to the water outlet, there is no danger to a qualified operator. The need of an inductive load in addition to a water load has been brought home to us by the troubles which have occurred with exciters of alternating sets through overheating when the generator was working on an inductive load. On a non-inductive load such exciters would be passed as satisfactory, but they would afterwards cause trouble on site. Stray losses in armature and pole pieces of generator are also frequently excessive on inductance load.

Among a number of interesting figures we note that Mr. Davis confirmed the apparent existence of capacity. Further accurate measurements to clear up this debated point would be serviceable.

The apparatus described by Mr. Keer has several suggestive features, but for convenient testing we are not in favour of using chemical solutions other than such as naturally come in canal water or other abundant supply. Special chemicals would necessitate cooling arrangements.

RULES OF THE SOCIETY OF GERMAN ELECTRICAL ENGINEERS, 1908.

By W. P. STEINTHAL, M.Sc., Associate Member.

(*Paper received from the* LEEDS LOCAL SECTION, *January 20, and read at Leeds on March 19, 1908.*)

During the summer of last year I was led to consider whether it was possible to take any steps to effect an improvement in electric installation work, more particularly as regards the cost of erection. Visits to the Continent, notably Germany and Switzerland, made me consider whether the methods employed in this country for the wiring of buildings, for electric light and power, were in any way handicapping the industry through the actual cost of installation, and I therefore decided to make some inquiries into this subject in the countries to which I have referred. Beyond the general conclusions at which I arrived, I do not propose to deal with these costs, as an exhaustive comparison would be quite sufficient in itself to form the basis of a paper for this Institution. In the course of my inquiry, however, my attention was directed to the rules for electric installation work drawn up by the Society of German Electrical Engineers (Verband Deutscher Elektrotechniker), which rules, I believe, are universally adopted in Germany by those responsible for installation work. As it cannot be denied that electricity both for light and power is more in general use in Germany than in this country, it struck me that it might be useful if these rules were brought to the notice of the members of the Institution of Electrical Engineers and were compared with the regulations in force in this country.

I propose, therefore, to put before the members a translation of these rules, to make a comparison with the rules of the I.E.E., and, finally, to make a few comments on the main points of difference which strike me as of importance. The rules of the V.D.E. are divided into two portions, dealing respectively with high and low tension, but I propose to confine myself to low tension, omitting the V.D.E. high-tension rules.

In the time at my disposal it is quite impossible for me to deal with the complete publication of the Society of German Electrical Engineers. This publication is divided as follows :—

1. Rules for erection and installation (Errichtungsvorschriften).
2. Rules for running electric installations (Betriebsvorschriften).
3. Sundry sets of rules dealing with various apparatus as regards type and method of manufacture.

The following is a translation of the first-named section, and it is this set of rules with which I propose to deal :—

I.—SCOPE OF THE REGULATIONS.

The following regulations hold good for electric installations, or parts of same, with the exception of underground networks of conductors, electric trams, electrochemical apparatus, mines, and laboratories, for which there are special regulations.

1. The paragraphs designated by letters contain fundamental rules which must be observed, while, on the other hand, the recommendations for installation work are contained in paragraphs designated by figures. The latter indicate how the rules are to be applied in the customary methods of installation so far as no special reasons exist for departure therefrom.

A. II.—DEFINITIONS.

a. "Low-tension installations" are those in which the effective working pressure between any conductor and earth cannot exceed 250 volts. The charging pressure in the case of accumulators is the pressure to be taken into account.

b. "Fireproof situations" are those which cannot be ignited, or which, if ignited, cannot maintain combustion.

c. "Bare conductors" are those overhead conductors outside any building which have no metallic sheathing or other protective covering.

Installations in the open in gardens, courtyards, in buildings, and so forth, are not included, so long as the distance of the point where protection starts is not greater than 33 ft.

d. "Electric power-rooms" are those in which electric machinery or apparatus is installed, and into which only authorised persons are admitted.

e. "Closed electric power-rooms" are those which are only occasionally entered by authorised persons, but which are usually under lock and key, and can only be opened by those persons who are duly authorised to enter.

f. "Power houses" are those which contain other than electric machinery as against power-rooms, and which are not regularly accessible to unauthorised persons.

g. "Saturated power- or work-rooms" are those in which industrial processes cause chemical deposits or chemical action which will endanger the normal insulation, or which will diminish the resistance of the bodies to earth of those persons engaged therein.

h. "Situations in which there is danger of fire" are those in which easily inflammable material is stored or manufactured or used for processes of manufacture, or in which inflammable mixtures of gases, vapours, dust, or fluff may occur.

i. "Situations in which there is danger of explosion" are those in which explosive material is stored, used for process of manufacture, or manufactured.

B. III.—GENERAL MEASURES OF PRECAUTION.

a. Protection against handling.

Those parts which are under pressure against earth, and which are not protected by insulating material, must be protected so as to render handling, where those parts are accessible, impossible. (For exception see paragraph XXVIII. *a.*)

1. Earthing consists in a sound connection to earth. Arrangements must be made so that the local conditions at the surface produce a decided and safe gradual fall of potential.
2. As earthplates, plates, convenient networks of pipes, bunches of wires, iron construction, rails, etc., will serve.
3. The cross-section of earthing conductors must be proportioned with due regard to the strength of the possible earth current. The smallest cross-section in electric power-rooms is to be 0·0248 sq. in. (16 sq. mm.), and 0·0062 sq. in. (4 sq. mm.) elsewhere, generally for copper conductors 0·00155 sq. in. (1 sq. mm.) for every 10 amperes may be reckoned.
4. The earthing conductors must be protected against mechanical or chemical injury.

IV.—Access of High-tension Current.

Special precautions must be adopted to prevent or render innocuous an access of high-tension current into a low-tension circuit.

1. Precautions may include earthing or short-circuiting or cut-out fuses, or similar devices, or the earthing of suitable points.

V.—Condition of Insulation.

Every installation must have a definite standard insulation value.

1. Measurements of insulation should be made with the pressure of supply, but with a minimum of 100 volts.
2. When measuring insulation to earth with direct current, where possible, the negative pole of the source of current should be connected to the conductor. When insulation measurement is being made with alternating current, the capacity of the circuit should be taken into consideration.
3. When in addition to the measurement of insulation between a conductor and earth, the insulation between two conductors of different potential is to be measured, all glow lamps, arc lamps, motors, and other current-consuming apparatus must be disconnected, and all fuses inserted and switches closed. Circuits must only be opened at one point, and that point

must be as near the middle as possible. The insulation resistance should conform to the conditions laid down in paragraph 4 following.

4. The insulation condition of a low-tension installation may be considered to be satisfactory, excepting that portion considered in paragraph 5, if the leakage current of any portion between the fuses or behind the last fuse, when using the pressure of supply for the exciting current, does not exceed 1 milliampere.

The value of the insulation resistance of such a portion of an installation as well as that of a distributing board should be at least 1,000 ohms × the pressure of supply. The measurement of insulation resistance of machines, batteries, transformers, is not included above.

5. Bare conductors, as well as those portions of an installation which are situated in damp places such as breweries, dyehouses, weaving-sheds, etc., need not conform to the conditions of paragraph 4. When an installation consists of a portion so situated, this portion should be disconnected, and the remainder should then conform to paragraph 4.

C. VI.—MACHINES, TRANSFORMERS, AND BATTERIES.

Electric Machines.

a. Electric machines must be so erected that they cannot, whilst running, set fire to any inflammable material.

VII.—Transformers.

VIII.—Accumulators.

a. Battery-rooms are considered to be closed electric power-rooms.

b. The separate cells must be insulated from the stands by means of non-hygroscopic supports, and the stands must be similarly insulated from earth.

c.

d. Cells must be so arranged that the attendant cannot simultaneously touch two points between which the difference of potential exceeds 250 volts.

e. Celluloid may not be used outside the electrolyte or for containing vessels for voltages above 16.

f. For the lighting of battery-rooms only lamps which burn *in vacuo* are permitted.

g. Battery-rooms must be well ventilated.

D. IX.—SWITCH AND DISTRIBUTION ARRANGEMENTS.

a. Switch and distribution boards must be mounted on fireproof material. Wood may be used for framing and cases.

* Note.—The paragraphs left blank refer to high tension.

b.

c. Switchboards and panels which are accessible from the back must have a clear space sufficiently high and broad to allow of free passage behind.

1. The distance between unprotected portions of the board carrying current and the wall at the back may be deemed to be sufficient if that distance, in the case of low tension, is approximately 39 in. (1 metre). If both sides of the passage hold unprotected current-carrying parts, the horizontal distance from board to wall should be 78 in. (2 metres).

d. Switchgear which is accessible from behind must be so arranged that the connections of the conductors can be inspected.

1. In the case of distributing boards which are not accessible from the back, the conductors should be connected up after the board is fixed, and the connections so arranged that they can be controlled and disconnected from the front.
2. Distributing boards outside power-rooms which are not accessible from behind should be so arranged that foreign bodies cannot come in contact with those portions which carry current.

e. The fuses and also the switches on boards must be labelled showing the rooms and groups of apparatus they control.

4. In the case of boards accessible from the back, the polarity of the busbars, etc., should be shown.

E. X.—APPARATUS.

General.

a. The outer current carrying portions of apparatus must be fixed on fireproof bases.

1. For description of bases for switches, plugs, and in power-rooms, see paragraphs XII. (1), XIII. (1), and XXXIII. (1).

b. The apparatus must be proportioned so as to prevent overheating with the heaviest rated current of the circuit.

c. All apparatus must be constructed or erected so as to prevent any possibility of injury to the person from sparks or hot molten metal or excess currents.

d. Apparatus must be constructed and erected so that there is a sufficiently good insulation between the connecting conductors and neighbouring parts of the building.

2. Care must be taken in the construction of the apparatus to prevent the handling of current-carrying portions.
3. For handles and coupling bars wood may be used.

XI.—Switches.

a. All switches, which serve to break circuit, must be constructed so as to prevent the maintenance of an arc.

1. Switches should have a quick break.
2. Switches should be placed in the apparatus itself or in a fixed conductor.

b. The nominal working current and pressure should be marked on the switch.

c. The parts of accessible switch covers and handles which are not earthed must be made of non-conducting material, or must be fitted with a durable insulating shield.

d. Switches for circuits must open each pole of a circuit which is under pressure to earth; switches for low tension which control small groups of incandescent lamps need not conform to this rule.

3. By small groups of incandescent lamps are meant those which are fused up to 6 amperes, as in paragraph XIV. (7), and which contain not more than 15 lamps in parallel.

e. Neutral conductors and earth conductors must contain no switches, or, if unavoidable, the switches must be coupled together with those in the other conductors. (For exception, see paragraph XXVIII. *e*.)

XII.—Controllers and Resistances.

a. Controllers and resistances in which the circuit may be broken must be so constructed that no arc is maintained in ordinary use.

b. The use of special switches (see paragraph XI. *d*) is, in the case of controllers and resistances, only necessary when the controllers do not themselves cut off each pole.

1. Impregnated wood without any oil-bath may be used for the covers of controlling switches, etc., for pressures up to 1,000 volts except in rooms which contain corrosive fumes. (See paragraph XXXIII. (1).)
2. The current-carrying parts of controllers, resistances, and heating apparatus should be protected with a cover of fireproof material; controllers, resistances, and heating apparatus should be mounted on fireproof material standing free, or mounted on fireproof walls sufficiently far away from any inflammable material.

XIII.—Sockets and Plugs.

a Plugs for the connection of movable conductors must be so constructed that they do not fit sockets made for a higher current strength. The normal current capacity and pressure should be marked on the socket and on the plug.

1. For plugs for low tension up to 20 amperes vulcanite or similar material may be used for the bases on which are mounted the current-carrying portions, provided the situation is dry and there is no possibility of heating from outside sources.

b. The necessary fuses may not be fixed in the movable portions.

2. When portable apparatus is to be connected the socket must be connected to the conductor and the plug to the apparatus.

c.

XIV.—Safety Fuses.

a. Fusible cut-outs and automatic cut-outs must be so proportioned and installed that the conductors which they protect cannot overheat; they must be so arranged that they break current without maintaining an arc.

1. The strength of the safety fuse must be proportioned to the current carried by the conductor which it controls; it must not be larger than shown in the table and regulation of paragraph XX.
2. Fusible cut-outs must be made of soft flexible metal, must not be connected direct to the fuse terminals, but must be soldered to contact pieces of copper or similar metal.
3. Fusible cut-outs which cannot be made dead must be so constructed and arranged that they can be taken out or replaced either with or without tools by the person in charge.

b. Fusible cut-outs for small low-tension currents must be so constructed that the insertion of a fuse for too high a current strength is impossible. (For exception see paragraph XXVIII. *h*.)

4. By small currents is meant those up to 30 amperes, but for currents under 6 amperes non-interchangeability is unnecessary.

c. The normal current capacity and maximum voltage must be marked on the fuse carrier.

d. Conductors must be protected by fusible or automatic cut-outs. (For exception see *g* and *h*).

5. In the case of low tension the fuses should be placed in accessible positions, and as far as possible grouped.

e. Fuses must be inserted at all points where the cross-section of the conductor is diminished; the fuse must be placed as near as possible to the point of reduction of cross-section.

6. In the case of tappings off a main, the fuse for the tapping may be connected to the main with a conductor of the cross-section of the tapping provided that the fuse is not more than 39 in. from the main and provided the conductor is protected from any inflammable material and is not a multiple conductor.

f. When reducing cross-section in all cases where the fuse protects the smaller conductor, no further fuses are necessary.

7. In the case of low tension several tappings may be protected by one fuse up to a maximum of 6 amperes, and in the case of further tappings or branches it is unnecessary to fuse again; in the case of larger fittings for electric light in exceptional cases common fuses may be used up to a maximum of 10 amperes provided the pressure does not exceed 125 volts.

g. Earthed conductors must generally contain no fuses.

h. The rules for fuses do not apply to conductors on switchboards or to the connecting leads between machines, transformers, cells, switchboards, etc., nor in cases where the melting of a fuse can cause danger in working.

XV.—

F. XVI.—LAMPS AND ACCESSORIES.

Holders and Incandescent Lamps.

a. The current-carrying parts of holders must be mounted on fireproof material and must be protected with a fireproof cover which cannot come in contact with the circuit.

1. Materials which are inflammable or hygroscopic, or which materially change their form when heated, should not be used in any part of a holder. (Compare paragraph X.)

b.

c. The current-carrying parts of a lamp must be protected from accidental handling.

d. Glow lamps in the neighbourhood of inflammable material must be protected by a cover which prevents contact of the lamp with such material.

e.

XVII.—Arc Lamps.

a. In places where the falling of hot pieces of carbon can cause danger, arrangements must be made to prevent this; in the case of enclosed arc lamps, no special arrangements need be made.

b. The cases of arc lamps must be insulated from the current-carrying parts and from the hangers.

1. Leading in holes for the conductors for lamps and lanterns must be arranged so as to prevent any possibility of damage to the insulation of the conductor; further, in the case of lamps and lanterns for outside lighting, care must be taken to prevent water getting in.

c. In cases where the conductors serve the purpose of hangers for the arc lamps, there must be no pull on the terminals.

d.

e.

XVIII.—Fittings, Pendants, and Hand Lamps.

a. On, or in, fittings conductors must only be used with a waterproof covering of the corresponding kind specified for a particular pressure.

If the conductors run on the outside of the fitting, they must be rigidly fastened and so arranged that they cannot be damaged by sharp edges.

1. The bore of the tubes of fittings, which are to carry conductors, must be large enough to allow of the conductors being drawn through without damage. The smallest permissible bore for two wires in the case of low tension is (6 mm.) 0·236 in.
2. In the case of low tension, tappings must be placed in central positions.
3.
4. Fittings must be so erected that the leading-in wires cannot be damaged by the movement of the fitting. Holders must be positively fastened to the fitting.

b.

c. If the weight of the fitting is carried by the conductor, the point of attachment of the conductor to its ceiling plate must have an arrangement so that there is no pull on the terminals.

d.

e. For hand lamps whose outer cover is of metal unearthed, the following rules are to be observed :—

The outer portion of the holder must be made of insulating material, and the current-carrying portions protected against handling.

The handles must be of insulating material. Internal metal parts of the handle must not project through the leading-in passage for the conductors.

The leading in of the flexible conductor must be so arranged that even rough handling does not cause a break at the point of entrance.

If the lamp is not fitted with a guard, hanging hook, or ring, it must be attached to an insulating base.

f. Switch holders are not permitted for hand lamps.

g.

G. XIX.—TYPE OF CONDUCTORS AND INSTALLATION.

Type of Conductor.

Where bare conductors are not admissible, the conductors must be covered with insulation whose durability and insulating properties conform with the rules previously given.

1. Below are different types of conductors for which particular rules hold good :—

Bare conductors (including those only protected against chemical action).

Rubber covered conductors, only to be used for erection on the surface of plaster in dry situations for pressures up to 125 volts.

Vulcanised rubber conductors (conductors with waterproof insulation) to be used for erection with pressures up to 1,000 volts, if in plaster only in tubes, and for portable apparatus for pressures up to 500 volts.

Vulcanised rubber flexible conductor, to be used for installation up to 1,000 volts and for portable apparatus up to 500 volts.

Fittings wire for wiring fittings up to 250 volts.

Pendant flexibles for pendants up to 250 volts (and sundry special conductors).

XX.—Proportions for Conductors.

Electric conductors must be proportioned in accordance with the regulations, and so that they have sufficient mechanical strength in each case and cannot heat unduly.

1. Insulated copper conductors not laid underground must not be loaded for any length of time beyond the current density given in table below.

Cross-section.		Amperes.	Corresponding Cross-section in Square Inches given for the Current in I.E.E. Rules, or nearest.
Sq. mm.	Sq. in		
0·75	0·00116	9	0·00424
1·00	0·00155	11	0·00554
1·50	0·00233	14	0·00783
2·50	0·00388	20	(21) 0·01250
4·00	0·00620	25	(27) 0·01700
6·00	0·00930	31	(33) 0·02200
10·00	0·01160	43	(40) 0·02800
16·00	0·02480	75	0·06000
25·00	0·03875	100	(108) 0·09400
35·00	0·05425	125	(130) 0·11700
50·00	0·07750	160	(157) 0·15000
70·00	0·10850	200	0·20000
95·00	0·14725	240	(238) 0·25000
120·00	0·18600	280	0·30000
150·00	0·23250	325	(320) 0·35000
240·00	0·37200	450	0·55000
500·00	0·77500	760	1·00000

N.B.—Figures in parenthesis give the actual I.E.E. current.

Bare copper conductors up to 0·0775 sq. in. (50 sq. mm.) must conform to the above rules. They do not, however, apply to bare conductors and aerial conductors of copper above 0·0775 sq. in. These must be proportioned so that when the maximum possible current is flowing they cannot assume a temperature dangerous to themselves or their surroundings.

2. For intermittent work a higher current density is permissible than that given in the table so long as there is no undue heating beyond what would take place with the current density given in that table.

3. The smallest permissible cross-section for copper conductors is as follows :—

For conductors on or in fittings, 0·00116 sq. in. (0·75 sq. mm.).

For insulated conductors in tubing or on insulators spaced not more than 39 in. apart, 0·0015 sq. in. (1 sq. mm.).

For bare conductors in buildings, also for insulated conductors in buildings or in the open where the points of support are greater distance apart than 39 in., 0·0062 sq. in. (4 sq. mm.).

For aerial conductors, low tension, 0·0093 sq. in. (6 sq. mm.).

4. In the case of conductors of other material than H.C. copper the cross-section must be so selected as regards strength and current density as to be equivalent to the above rules for the particular metal or alloy to be used.

XXI.—General Rules for Erection of Conductors.

a. Fixed conductors must be protected from mechanical damage either by their situation or sheathing. Conductors whose potential is above that of the earth and which are within reach of the hand must have a special protective covering. (For exceptions see paragraph VIII. *d*, XXVIII. *g*, and XXX. *a*.)

1. The metal cover of armoured lead cables serves as sufficient protection. In the case of low tension, conduits serve as sufficient protection.

b.

c. Portable and movable conductors which are tapped off fixed conductors only require special protection against rough usage.

d. Earthed conductors may be fixed direct to buildings or in the ground, nevertheless they must be protected from damage caused by the supports, etc.

3.

e. Unearthed bare conductors must only be carried upon reliable insulators.

f. Unearthed bare conductors must be kept a certain distance from the buildings or any ironwork according to the length of span, strength of conductors, and pressure.

4. Unearthed bare conductors should, as a general rule, be kept 8 in. from one another in the case of 20 ft. and over spans, 6 in. in the case of 13 to 20 ft. spans, 4 in. in smaller spans; in every case, however, the distance from the building must be 2 in. (Compare paragraph XXXI. (2).)

5. In the case of connectors between cells, machines, switchboards, and on switchboards, and also in the case of all regulating conductors, feeders, and distributing conductors, heavy copper busbars and wires may be erected closer together.

Smaller distances between conductors are only allowable when there is a reliable insulating distance-piece at intervals of not more than 39 in.

g. Insulated conductors may be run open on insulators or laid in tubes.

8. Conductors should, as a general rule, be erected so that they can be altered. (Compare paragraph XXVI. (2).)

9. Insulated conductors erected open must be separated in the case of low tension at least ¾ in. from one another, and when in buildings ½ in. from the wall.

10. Rubber-covered conductors (§ XIX., 1) should only be laid in tubes above the plaster. Vulcanised rubber conductors may be laid in insulating or metal tubes under plaster.

11. Insulated conductors with metallic protection, which are used for connecting up machinery and apparatus in dry-rooms or in the open, so long as they are under permanent supervision (such as cranes, travellers, etc.), may be connected directly to walls or frameworks with saddles.

12. In cases where the bunching of conductors is unavoidable (such as regulating rheostats, etc.), conductors may be connected so that they can move so long as they cannot materially alter their position.

13.

h. Conductors or cables for single- or multiple-phase currents which have a metallic sheath, or are laid in iron conduits, must have the various conductors of the circuit under a single metallic covering, care being taken that in other respects they are not subject to chance of dangerous overheating.

i. Jointing of conductors or tappings off conductors may only be made by soldering, binding screws, or similar connections.

14. Connection of conductors to apparatus machines, busbars, and current-consuming devices must be made with screws or similar contrivances. Flexibles or wire cords up to 0·0093 sq. in. (6 sq. mm.) and single wires up to 0·039 sq. in. (25 sq. mm.) cross-section of copper may be fastened with eyes. Cords above 0·0093 sq. in. and wires over 0·039 sq. in. must be fastened to cable sockets. In the case of all kinds

of flexible cords, the single strands of the conductor when they are not fixed into cable sockets should be soldered together at the ends.

15. Jointing of flexible cords to one another or tappings off should be made with binding terminals mounted on insulating bases. In and on fittings solder is permissible for low-tension work.

k. When jointing or tapping insulated conductors the joint should be insulated as far as possible to the same extent as the conductor itself.

l. Movable conductors should only be jointed up to fixed conductors with detachable connectors.

m. Only one movable conductor may be connected to a single plug. Tappings off and lengthenings of movable conductors may only be made with properly designed multiple plugs.

n. The crossings of current-carrying conductors must be made so as to prevent contact one with the other.

o. Precautions must be taken to prevent a low-tension conductor being endangered by a high-tension conductor.

16. Government regulations for the protection of telephone and telegraph wires.

XXII.—Aerial Conductors.

a. Unearthed aerial conductors may only be run on porcelain bells or similar arrangements.

b. Aerial conductors and apparatus connected thereto must be erected so as to be inaccessible without special ladders, and so forth, to people standing on the ground, on roofs, outbuildings, windows, etc.

When crossing a road they must be a specified height above the ground or they must have a special method of protection.

1.

c.

d. Conductors, guard wires, and their supports, must have sufficient strength (taking also into consideration wind pressure and weight of snow).

2. Aerial conductors may be loaded above the figures of table in paragraph XX. (1) so long as their mechanical strength suffers no injury from the load.

3. For proportions for aerial conductors see "Rules for Aerials."

e. Aerial conductors must, having due regard to the generators, motors, etc., connected thereto, be protected by lightning arresters which after a discharge return to their normal position, ready for the next discharge.

4. When different phases or poles are protected by neighbouring arresters, care must be taken that there is no possible dangerous tension between the earth plates which could affect a person walking on the ground.

f.

g.

h. When aerial conductors run parallel with or across other conductors, proper arrangements must be made to prevent danger should they come into contact through the breaking of a wire and for any other reason.

i.

k.

l.

XXIII.—Installations in the Open.

a. In the open conductors must have cut-off switches.

b. Fixed multiple conductors are not permissible in the open.

c.

1. Unprotected conductors in the open must be guarded to prevent handling.
2. Unprotected low-tension conductors in the open must be so erected that they cannot be touched without the aid of ladders, etc.
3.
4. In the case of advertising signs and similar installations the conductors may be proportioned for the largest value of the current consumed by the device.
5. Apparatus should, as a general rule, not be erected low down, but where this is unavoidable special precautions should be taken to ensure good insulation and to prevent handling or damage from weather.

XXIV.—Conductors in Buildings.

a. In living-rooms unearthed bare conductors are not permitted.

b.

c. At tapping-points any possible drag on the tapping must be counteracted.

d. Through walls, ceilings, and floors the conductors must be protected against damp, mechanical and chemical injury. The same applies to conductors on the surface.

1. The conductors leading through walls, etc., either have their protective coverings continuous through the wall, etc., or they must run through insulating tubes, and only one conductor may be run through one tube.

 In damp rooms the tubes must be of porcelain or similar material whose surface does not allow any appreciable

leakage, or the conductors must run free through a suitable conduit.

Above floors the tubes should project at least 4 in. (10 cm.) and be adequately protected from mechanical injury.

XXV.—Insulators, etc.

a. Wood supports are not permitted.

b. Staples are only permitted for earthed conductors and so long as precautions are taken to prevent mechanical or chemical injury through the method of fastening.

c. Insulators of various kinds must be made of porcelain, glass, or similar material.

d.

e. Bells insulators must be erected so as to prevent any accumulation of water.

f. Insulators must hold the conductors a sufficient distance apart from one another and from the building, etc.

1. In running conductors on reels along the wall there should be a point of support at least every 32 in. (80 cm.). In running on ceilings this distance may be increased in special cases.
2. Multiple conductors should not be erected so that individual cores are pressed against one another. Metal-binding wire may not be used for unarmoured multiple conductors.

XXVI.—Conduits.

a. Papier-mâché conduits must have a metal sheathing.

b.

c. In the same tube only conductors belonging to the same circuit may be placed. (Compare paragraph XXI.) Exceptions (see paragraph XXVIII. *i*) are permitted in the case of switchgear in power-rooms.

d. Joints inside conduits, except in fittings, are not permitted.

1. Conduits should be installed so as to prevent any internal accumulation of water.
2. Metallic and insulating conduits should be arranged as regards bore and as regards the number and radius of bends so that the wires can be drawn in or out with ease. In the case of conductors of a larger cross-section than 16 sq. mm. this is unnecessary so long as the conduit is on the surface and accessible throughout its length. The tubes must be fitted with suitable bushes so that the insulation of the conductors cannot be damaged by sharp edges.
3. Tubes to hold more than a single wire should be at least 11 mm. internal diameter.
4. In the case of surface work, where a single length is protected by conduit, such conduit may be of smaller dimensions.

XXVII.—Cables.

a. Plain and compounded lead cables must only be installed so that they are protected against mechanical and chemical injury. (Compare paragraph XXI. *h.*)

1. Lead-covered cables other than those insulated with rubber should be fitted with suitable end connectors to prevent the admission of moisture, ensuring at the same time a sound electrical connection.

b. Care must be taken to prevent injury to the lead sheath at the point of fastening. Pipe hooks are not permissible.

c. Test wires must be treated in the same way as the cables.

H. XXVIII.—METHODS TO BE EMPLOYED IN VARIOUS KINDS OF SITUATIONS.

For the following situations, in addition to the general regulations, the subjoined rules are to be observed :—

Electric Power-rooms.

a. As against paragraph III. *a*, in the case of low tension live wires need not be protected against handling.

b.

c.

d. Switches in power-rooms need only follow the rules under paragraph XI. in so far as their current-carrying capacity is concerned. Attention must be paid not only to the current carried, but also to the current which the switch may have to break.

1. Switches need not have a quick break.

e. As against paragraph XI. *e* neutral and earthed conductors may be fitted with switchgear.

f. As against paragraph XII. *b* in power-rooms no special switches are necessary for controllers which do not work on both poles.

2. The rules under paragraph XII. (2) do not apply to power-rooms.

g. The protective covering specified under paragraph XXI. *a* only applies in so far as protection against mechanical injury is concerned.

h. Non-interchangeability of fuses does not apply to conductors in power-rooms.

i. For switch and signal circuits conductors of different circuits may be run in one tube.

XXIX.—Closed Electric Power-rooms.

a.

b.

XXX.—Power Houses.

a. As against paragraph XXI. *a* for low tension, the connecting conductors to machines which are within reach may be unprotected so long as the insulation cannot be damaged.

b.

XXXI.—Damp Rooms.

a. Unearthed conductors leading to damp rooms must be switched on each pole.

b. Insulated conductors must be covered with waterproof insulation suitable to the working pressure.

c. Multiple conductors must not be rigidly fixed.

d. Movable conductors must be specially protected with a flexible covering.

1. Conductors laid open on the surface must be specially protected against handling. (See paragraph III.)
2. Unearthed conductors laid as above should be fixed on suitable insulators which hold the conductors at least 5 c.m. (2 in.) apart and 5 c.m. (2 in.) from the wall. (Compare paragraph XXI. (4).) They may be covered with damp-proof paint.
3. Apparatus should not be brought into damp rooms, but where this is unavoidable particular precautions should be taken against handling or damage from access of moisture to the apparatus.

XXXII.—Saturated Power Houses and Situations.

For these, in addition to the rules under paragraph XXXI., the following rules must be observed :—

a. At particular points warning notices must be erected as regards careful handling of the electrical apparatus.

b. Switch lamp holders are not permitted.

c. Arc lamps must be out of reach whilst running, and must be fitted with disconnecting contacts for trimming purposes which entirely disconnect them from live circuits.

d.

XXXIII.—Power Houses, etc., with Corrosive Fumes.

a. Fixed conductors must be adequately protected against chemical injury from the particular fumes present.

b. Hand lamps must only be connected by conductors with proper protection against chemical injury.

c.

XXXIV.—Situations in which there is Danger of Fire.

a. The neighbourhood of dynamos, motors, transformers, converters etc., must be kept free from inflammable material.

b. Fuses, switches, and similar apparatus which break circuit must have closed fireproof cases.

c. Bare conductors are not allowable. Insulated conductors must have watertight covering.

1. Special precautions should be taken against mechanical injury.

d.

XXXV.—SITUATIONS IN WHICH THERE IS DANGER OF EXPLOSION.

a. Dynamos, motors, transformers, converters, rheostats, switches, fuses, and similar apparatus which break circuit may only be used if constructed to avoid all possibility of their causing an explosion.

b. Conductors must have watertight protection suitable for the working pressure, and must only be erected in conduit. Multiple conductors are not permissible.

c. Only lamps burning *in vacuo* may be used. They must be fitted in fittings which completely protect both lamp and holder.

d.

XXXVI.—SHOP WINDOWS, WAREHOUSES, AND SIMILAR SITUATIONS CONTAINING EASILY INFLAMMABLE MATERIAL.

a. Fixed conductors which may come in contact with easily inflammable material must be laid in conduit right up to the holder and socket.

b. Fittings, etc., which can be moved must be connected with metal covers, or, at all events, specially protected conductors. In the first case the metal cover of the conductor must make a metallic connection with the cover of the holder, and the metallic sheathing must be earthed. In the second case flexible conductors must be used with a waterproof covering and an additional cover of leather or similar material to guard against mechanical injury.

c. Sundry switches, fuses, plugs, etc., must have protecting covers, and must be fixed where they cannot come in contact with inflammable material.

d.

N.B.—Paragraphs left blank refer to high tension.

It will be observed that these regulations are very minute in detail, far more so than the equivalent rules of the I.E.E. It should, however, be explained that whilst some of these rules are actual regulations to be observed (see paragraphs headed by letters), a number are merely recommendations (paragraphs headed by numbers).

In the first paragraph of the I.E.E. rules there are the words: "They are intended to include only such requirements and precautions as are generally necessary, but they are intended neither to take the place of a detailed specification nor to instruct untrained

persons." An examination of the German rules will show that the authorities responsible for those rules evidently set about their work with a different object in view from that set forth in the passage just quoted from the rules of the I.E.E., for it is evident that if an installation is erected to the regulations of the German Society, no further specification could under any circumstances be required. As far as the rules themselves are concerned, it will be found that the general tendency is very similar to that of the I.E.E. rules. But there are notable differences, and it is the most important of these to which I wish to call attention. I do not propose to offer any criticism on these differences, my object being rather to call for an expression of opinion on the points raised.

1. *Current Density.*—On reference to the table in paragraph XX. (1), it will be noticed that I have given the equivalent square inches for square millimetres and the I.E.E. equivalent cross-section required for the particular currents given as maximum by the German rules for various cross-sections of conductors. An examination of these figures shows that from 9 amperes to 20 amperes the current density is three times or more, from 20 amperes to 200 amperes twice or more, from 200 amperes to 240 amperes one and a half times or more, and for 500 amperes 1·3 times that of the I.E.E. rules. That is to say, that the amount of copper used under V.D.E. rules is considerably less than under the rules of the I.E.E. This means in effect that the loss of pressure at the end of a circuit, about which I can find nothing stated in the V.D.E. rules, is allowed to be considerably greater than in our case. This is a very noticeable difference between the two sets of rules.

2. *Insulation.*—It may, I think, be assumed that rubber-covered wires have been entirely discarded in this country except for flexibles. But in Germany they are retained to some extent for surface work up to 110 volts. The use of this rubber-covered wire is what is referred to in this country as "Continental wiring with flexibles." The use of the word "flexible" here is really misleading as the conductors are not flexibles in our meaning of the word. They are merely rubber-insulated wires as against vulcanised rubber wires. For installations up to 125 volts where the work is done on the surface the use of this rubber-covered wire, fixed on porcelain bobbins, is very common. There can be no question that this method of installation is cheap, and, if properly carried out, neat and perfectly sound from an electrical point of view.

Now, with regard to the actual insulation of conductors, the German Society have fairly definite specifications. The point, however, to which I wish to draw attention is the radial thickness of insulation which is shown comparatively in the table on the following page.

This table shows that the thickness of insulation required is appreciably smaller in the case of the German rules. The general conclusion at which we arrive is, therefore, that the German rules allow a very appreciable diminution in cost of installation as far as conductors are concerned, as compared with the usual practice in this country.

TABLE FOR RADIAL THICKNESS OF INSULATION.

Cross-section. Sq. mm.	Mils. V.D.E.	Mils. I.E.E.
1·0	31	40
1·5	31	41
2·5	39	44
4·0	39	47
6·0	39	47
10·0	47	52
16·0	47	62
25·0	55	71
35·0	55	76
50·0	62	80
70·0	62	87
95·0	70	94
120·0	70	101
150·0	78	107
240·0	94	125
500·0	125	141

I think we rather err on the safe side in the case of small cables, and it will be interesting to hear whether this view finds support from members.

3. *Flexibles.*—The very exhaustive paper read by Professor Schwartz last year to this Institution deals very fully with the subject of flexibles, and in Appendix C of that paper will be found the German rules as they stood in 1905. The 1908 rules contain no appreciable modification. The paper to which I refer goes very fully into details on the subject of flexibles, and I only desire to point out one German rule in particular which relates to the supporting of a fitting by means of an additional wire which carries no current in addition to the actual conductor carrying the current. This appears to me to be an important point to which I find no reference in the I.E.E. rules.

4. *Insulation Resistance.*—On reference to paragraph V. on the testing of insulation resistance, it will be noticed that the requirements are put in a rather different form from that to which we are accustomed in this country. They do not base their tests according to numbers of points, but they require that the leakage current should not exceed 1 milliampere between any two fuses, and further, that a distributing board should have an insulation resistance of 1,000 ohms multiplied by the pressure of supply. In measuring the leakage current, it is specified that the minimum pressure for the exciting current should be 100 volts. An examination of these requirements shows that more particularly in small installations the Germans are content with a lower test than we are in this country. This possibly may be a logical conclusion drawn from the fact that the grade of insulation of conductors used is lower. In this connection it would be interesting to inquire whether in the use of a higher grade of

cable and in the consequent higher insulation tests required, we are erring on the safe side and making our installation work unnecessarily expensive.

5. Generally, one may call attention to the following points in the rules:—

Paragraph III. 3.—Proportions given for earth wires.

Paragraph VIII. *d*.—This regulation with regard to the erection of cells appears to be a useful one.

Paragraph XI. *b*.—This regulation appears to be a useful one, referring to a practice which is more or less non-existent among English manufacturers. I consider it would be of great utility to the contracting engineer if switches and other accessories were labelled with their rated capacity and the voltage for which they are designed. It would be of use for stock-keeping purposes and for insuring in cases of repairing and installation work that the correct size of fuse, switch, or plug is sent out. Anything of this kind which assists the contractor is worthy of attention, as it must be admitted with regret that the average wireman available is neither as well trained nor as intelligent as one would desire.

Paragraph XIII. *a*.—This rule deserves mention, as in my opinion sufficient care is not taken with regard to sockets and their plugs.

Paragraph XIV.—Under this heading there are several points worthy of attention. In the first place an examination of these rules points to the use of the Edison screw type of fuse plug, and my own observations of installations in Germany tell me that this type of fuse is used almost universally. The point to be particularly noticed is the value attached to non-interchangeability. The replacement of fuses is treated in this country in a most haphazard fashion, and I am inclined to think that the Edison screw type of fuse is more scientific, and ensures more certain working and proper replacement. Of course the above remarks apply entirely to small branch circuits. The German rules (see paragraph XIV. *a* 2) insist upon proper contact pieces of copper being used in connection with fusible wires.

Paragraph XVIII. *f*.—It is interesting to note that switch lamp holders are not permitted for use with hand lamps.

Paragraph XXVI. *a*.—The use of papier-mâché conduit with either a brass or an iron sheath appears to be very common in Germany. This type of conduit is, I believe, sold in this country under a trade mark "Adnil." From inquiries I have made this conduit does not appear to offer any advantage as regards price. It is possible that there may be a saving in cost of labour with this type of conduit over the steel conduit in general use here.

There are, no doubt, many points in the German rules which call for criticism, but in a short paper such as this, I have only referred to those points which to my mind are more conspicuous than others.

After having considered the general rules for installation work, I should like shortly to consider the particular regulations referring to insulated conductors for inside work.

The special regulations with which I wish to deal come under the heading of "Rules for Conductors," paragraphs A (part only), B, C, D, and "Rules for Copper."

The rules are as follows:—

RULES FOR CONDUCTORS.

A. Rules for Rubber-covered and Vulcanised Rubber-covered Conductors.

1. *Rubber-covered Conductors suitable for Permanent Installation outside Plaster in Dry Rooms with Pressures up to 125 Volts.*—Rubber-covered conductors may be of solid wire for cross-sections from 0·00155 (No. 18) to 0·0248 (No. 7) sq. in. (1 to 16 sq. mm.), or consist of stranded conductors for cross-sections from 0·0015 to 0·2325 sq. in. (1 to 150 sq. mm.). They may not be used for multiple core conductors.

The copper is to be tinned, then lapped with cotton, and over this taped with finest pure unvulcanised "Para" strip. In taping successive windings must overlap one another to the extent of at least 0·078 in. (2 mm.). Over the rubber there must be a cotton lapping and then a braiding of cotton, hemp, or similar material suitably served with compound.

Rubber-covered conductors are not subjected to a pressure test.

The rubber taping must conform to the following table:—

Cross-section of Copper.				Minimum Weight of Rubber in each 100 metre Length.		Minimum Number of Strands for Cables.
Sq. mm	Sq. in.			Grams.	Oz.	
1·0	0·00155	1/18	+	130	4·55	7
1·5	0·00233	1/17	+	155	5·43	7
2·5	0·00388	1/15	+	190	6·65	7
4·0	0·00620	7/20½	—	230	8·05	7
6·0	0·00930	7/19	—	280	9·80	7
10·0	0·01550	19/21	+	340	11·90	7
16·0	0·02480	19/19	—	420	14·70	7
25·0	0·03875	37/20	—	550	19·25	7
35·0	0·05425	19/16	+	650	22·75	19
50·0	0·07750	19/15	—	800	28·00	19
70·0	0·10850	19/·082"	—	1,000	35·00	19
95·0	0·15423	37/15		1,200	42·00	19
120·0	0.18600	37/14		1,400	49·00	19
150·0	0·23250	91/17	—	1,550	54·30	19

N.B.—In heavy type are the nearest S.W.G. equivalents; + means slightly higher, — means slightly lower.

The weight is taken from the average weight of rubber on five pieces of 39·3 in. (1 m.) long each, picked indiscriminately from the length under test.

2. *Vulcanised Rubber-covered Conductors (Generally).*—Vulcanised rubber-covered conductors may be solid wire for cross-sections from 0·00155 (No. 18) to 0·0248 (No. 7) sq. in. (1 to 16 sq. mm.), or consist of stranded conductor for cross-sections from 0·10155 to 1·55 sq. in. (1 to 1,000 sq. mm.).

Working Pressure in 1,000 Volts.	Test Pressure in 1,000 Volts.
1	2
2	4
3	6
4	8
5	9
6	10
7	12
8	13
10	15
12	18

The copper is to be tinned, covered with water-tight vulcanised rubber and waterproof tape, then braided with cotton, hemp, or suitable material served with compound.

In the case of multiple core conductors the braiding may be put on overall.

Copper Cross-section.				Min. Number of Wires of Stranded Cond.	Thickness of Rubber.				
					At least			Not more than	
Sq. mm.	Sq. in.				mm.	mils.		mm.	mils.
1·0	0·00155	1/18	+	7	0·8	31	**35**	1·1	43
1·5	0·00233	1/17	+	7	0·8	31	**36**	1·1	43
2·5	0·00388	1/15	+	7	1·0	39	**37**	1·4	55
4·0	0·00620	7/20½	−	7	1·0	39	**40**	1·4	55
6·0	0·00930	7/19	−	7	1·0	39	**42**	1·4	55
10·0	0·01550	19/21	+	7	1·2	47	**46**	1·7	66
16·0	0·02480	19/19	−	7	1·2	47	**50**	1·7	66
25·0	0·03875	37/20	−	7	1·4	55	**55**	2·0	78
35·0	0·05425	19/16	+	19	1·4	55	**62**	2·0	78
50·0	0·07750	19/15	−	19	1·6	62	**66**	2·3	90
70·0	0·10850	19/·082"	−	19	1·6	62	**72**	2·3	90
95·0	0·15423	37/15		19	1·8	70	**80**	2·6	101
120·0	0·18600	37/14		37	1·8	70	**87**	2·6	101
150·0	0·23250	91/17	−	37	2·0	78	**92**	2·8	109
185·0	0·28675	91/16	+	37	2·2	86	**98**	3·0	117
240·0	0·37200	91/15	+	61	2·4	94	**110**	3·2	125
310·0	0·48050	37/10	+	61	2·6	101	**121**	3·4	133
400·0	0·62000	91/13		61	2·8	109	**126**	3·6	140
500·0	0·77500	91/12	+	91	3·2	125	**133**	4·0	156
625·0	0·96875	91/11	+	91	3·2	125	**140**	4·0	156
800·0	1·24000	(?)		127	3·5	137	(?)	4·5	176
1,000·0	1·55000	(?)		127	3·5	137	(?)	4·5	176

N.B.—Heavy figures give approximate I.E.E. equivalent for 250 volts.

Each conductor must be tested after lying for twenty-four hours in water, and must withstand an alternating current of a pressure as specified in the table at the top of page 188, between copper and water, the temperature of which must not exceed 25° C.

Vulcanised rubber-covered conductors are suitable for permanent installation for pressures up to 1,000 volts, and for connecting portable apparatus up to 500 volts.

The table gives the thickness of rubber required.

B.—Rules for Vulcanised Rubber-covered Flexible Conductors.

These are suitable for permanent installation for pressures up to 1,000 volts and for connecting portable apparatus up to 500 volts. They may be used for cross-sections from 0·00155 to 0·0093 sq. in. (1 to 6 sq. mm.).

The core consists of tinned copper wires of not more than 0·0117 in. (No. 30 S.W.G.) (0·3 mm.) diameter twisted together, the copper lapped with cotton and covered with a water-tight vulcanised rubber coating. Each conductor must have a cover of fibrous material over the rubber (yarn, silk, cotton, etc.).

In the case of twisted multiple flexibles this covering must consist of a single braiding. Round or oval multiple flexibles must, in addition, have a common overall braiding.

Each conductor must be tested after 24 hours' immersion in water with 2,000 volts alternating between copper and water for half an hour, the temperature of the water not exceeding 25° C.

Required thickness of rubber as table following :—

Cross-section of Copper.		Thickness of Rubber.			
		At least		Not more than	
Sq. mm.	Sq. in.	mm.	mils.	mm.	mils.
1·0	0·00155	0·8	31	1·1	43
1·5	0·00233	0·8	31	1·1	43
2·5	0·00388	1·0	39	1·4	55
4·0	0·00620	1·0	39	1·4	55
6·0	0·00930	1·0	39	1·4	55

Current density as in table under A.

C.—Rules for Fittings Wire.

Fittings wire is suitable for wiring on or inside fittings for pressures up to 250 volts. The fittings wire consists of solid or stranded con-

ductor of 0·00147 sq. in. (0·75 sq. mm.) cross-section. The copper core is tinned and covered with vulcanised rubber 0·0234 in. (0·6 mm.) thick. Over the rubber is a braiding of cotton, hemp, silk, or similar material, which may be served with compound. The outside diameter of a single conductor must not exceed 0·105 in. (2·7 mm.). The conductors may be multiple.

A twin fittings wire may consist of two conductors laid side by side with a common braiding as above overall. The greatest dimension overall must not exceed 0·21 in. (5·4 mm.).

Fittings wire must be tested in a dry situation for half an hour with 1,000 volts alternating. In testing ordinary fittings wire, two pieces 6 ft. 4½ in. (5 metres long) are to be twisted together.

Current density as in table under A.

D.—Rules for Pendant Flexibles.

These are suitable for flexible pendants up to 250 volts. Pendant flexibles have a cross-section of copper of 0·00147 sq. in. (0·75 sq. mm.). The copper consists of tinned copper wires not more than 0·0117 in. (No. 30 S.W.G.) (0·3 mm.) diameter twisted together. The copper is lapped with cotton and covered with vulcanised rubber 0·0234 in. (0·6 mm.) thick. The two conductors are twisted together with a cord to carry the weight, and the whole braided with a common covering of cotton, hemp, or silk. If the weight-carrying cord is of metal it must be braided. The common braiding may be dispensed with if each conductor is separately braided. Flexible for counter-weight pendants must be so flexible that a single conductor can run easily over a pulley 1 in. (25 mm.) diameter, or a twin flexible over a 1·4 in. (35 mm.) diameter pulley.

Pendant flexible must withstand in a dry situation 1,000 volts alternating.

Current density as in table under A.

RULES FOR COPPER.

Conducting copper must not have a greater resistance than 17·5 ohms per 1,100 yards (kilometre) length of 0·00155 sq. in. (1 sq. mm.) cross-section at 15° C.

At temperature t the resistance R_t must be calculated from the formula—

$$R_{15} = \frac{R_t}{1 + 0{\cdot}004\,(t - 15)}.$$

This is practically the same as the E.S.C. standard: "A wire 1 metre long weighing 1 gram. has a resistance of 0·1508 ohm at 15·6° C."

I have indicated by figures in heavy type in paragraph A (1) the S.W.G. equivalents for the cross-sections approximately. In paragraph A (2) I have done the same, and also added for comparison the I.E.E. equivalent thicknesses in mils for 250-volt conductors. It must here be

borne in mind that the thicknesses given by the German rules hold good up to 1,000 volts.

On examination of the rules and the comparison with the I.E.E. figures it will be found that the general tendency is in the direction of higher current density and thinner insulation. Thus the cables used under German regulations would be a great deal cheaper than under the regulations of this Institution. But there is a further point. It is noticeable that no mention is made in the German rules of a layer of pure rubber between the copper and the vulcanised rubber.

A very pertinent question arises out of these comparisons, namely, whether the extra cost involved by our practice is necessary or essential for the security, durability, and efficiency of installations. I feel satisfied in my own mind that the German regulations are the result of experience and careful investigation, and it will be interesting to hear the views of members of this Institution as to how far it would be advisable for us to modify our existing rules. There is one point which I think must be taken into consideration, and that is the question of climate, which, generally speaking, may be taken as dryer than the climate of this country.

With regard to flexibles, it will be observed that there are three distinct kinds of wire named :—

1. Vulcanised rubber flexible (Gummi-ader Schnüre).
2. Fittings wire (Fassungs-adern).
3. Pendant flexible (Pendel Schnüre).

The first is the conductor used for permanent installation on porcelain bobbins, a practice or method of installation which is very little used in this country, and which, I think, is very admirably adapted for certain classes of work.

In connection with the third, the rules provide for the introduction of a support (Tragschnur) to carry the weight of a pendant. It is further to be noticed that no mention is made of the insulation of flexible conductors with pure rubber.

Discussion at Leeds.

Mr. W. H. Campion.

Mr. W. H. Campion: It seems to me that the chief object of the paper is to show whether installations can be erected cheaper, and, of course, if they can, it will have the effect of increasing considerably the number of consumers connected to the mains. But there is always the consideration that if one goes in for the cheaper installation it may eventually bring more discredit, so that after all it seems to me that the only point is the difference of the current density of the V.D.E. rules and the I.E.E. rules. It seems that the Germans use a rating regardless of pressure drop, but if this is put into casing there will be trouble, and as a rule the trouble is not with the contracting engineer, but between the fire insurance company and the man in whose place the installation is, and the central station generally hears

Mr. Campion.

most about it. Of course, if a good system can be brought out for cheapening installations everybody will welcome it; but I must say that all the wiring I have seen on the Continent, including the flexible wiring, has always been in connection with a low voltage—about 100—and it is pretty much the same in America, where they allow a good deal of haphazard work. As they seem to have adopted elaborate means in some cases, I think they might have extended it a little farther. Regarding bare conductors, one would like to have a little more information where these are used in damp places, such as breweries, dyehouses, etc.

Regarding the switchboards, I think the polarity of the busbar should be shown, and that may possibly keep people off. I think, however, they would all have to be marked red, for if blue were taken for a negative sign it would probably not prevent the men from getting a shock. The Verband Deutscher Elektrotechniker suggest that the nominal working current and pressure should be marked on the switch. That is where we have spent a good deal more money than we need have done for a long time, 5-ampere switches being put on for one 8-c.p. lamp, and so on. I know that there are smaller switches, but even now they are seldom used; but perhaps if the grading had been stamped on these goods people would not have put them in in such places where smaller ones would have answered the purpose.

They stipulate that plugs for the connection of movable conductors must be so constructed that they do not fit the sockets made for a higher current strength. The trouble is, no doubt, felt even with heating apparatus to save any one installing separate wiring for a cheap rate of heating, though one cannot get this interchangeability with plugs. I know 5-ampere plugs and 10-ampere plugs and higher can be got, but there is not that variety that we can pick to any extent. The paragraph regarding fuses is certainly very instructive. I see they make a great point of the protection from any inflammable material. I think a good many of us will have noticed the amount of inflammable material that is put on to the lamps, particularly in showrooms, windows, etc., and it is astonishing what they will stand before it is set alight.

The rules certainly are very minute in detail. For instance, fittings must be so erected that the leading-in wires cannot be damaged by the movement of the fitting. It is done a good deal with us, but the cord grips are so cut away that they are of very little use. All the care taken with regard to hand lamps is certainly a point to be watched.

I suggest that with the current density they have taken for the conductors they are relying more or less on intermittent loads, and of course one knows that it takes a good deal before wire will warm up. I think that the current must not be maintained too long or the casing containing the wires will become heated.

Another point is that they stipulate 39 in. (1 metre) apart for a case of safety. The Board of Trade have always taken 6 ft., and it is most inconvenient for those that have worked to it.

The insulated conductors may be run open on insulators or laid in

tubes. I find that they are not the latter as a rule. There are very few instances on the Continent, and they are mostly stapled up, and, unless these staples are put in very carefully, they must have trouble. Mr. Campion.

With regard to radial thickness of insulation, I think it would be a good thing if more pressure could be brought to bear, but we shall have to look to the Cable Makers' Association to do anything in England. If it was brought to their notice some good might result, but I am of opinion that it rests with them entirely.

Mr. S. W. CUTTRISS: These rules stipulate that the nominal working current and pressure should be marked on the switches. I think that is a useful rule, because there is no doubt that switches are often used for higher current densities than those for which they are intended. If the switch was marked for the purpose for which it was made, I think it would prevent the use of those too small for the work. The same remark applies to plugs. I see they recommend the Edison form of plug fuse, but apparently not for sub-circuits for house purposes. We should not like to have enclosed fuses for these, as our present form is very convenient. For heavier currents it is useful to have them standardised, but there is a good deal to be said on both sides. Mr. Cuttriss.

The plan of having an independent third wire in flexibles to support the weight of the fitting I think might be adopted to a great extent in this country, because flexibles are undoubtedly overloaded in many cases, and the fittings have been known to drop.

The insulation of conductors is, to my mind, one of the most important points in the whole paper, but the Germans do not appear to be so particular as we are in that respect. They allow a lower insulation, and I am afraid it means a lower quality of dielectric. We know that a certain specific insulation does not necessarily mean a good quality of material. Unfortunately cables are among the most difficult things we have to deal with as regards knowing what we are getting. The cable may pass a certain insulation test, but at the same time the covering may be of such a quality that it is very little good and will not last. It does not pay to put in a low grade of insulation, because the important point is not the insulation test when it is installed but the length of time the insulation will last.

With regard to installing conductors, I see there is no mention of wood-casing. I cannot speak from experience because I have not seen Continental installations, but I should gather from the rules that it is not used. Wood-casing, although despised a good deal by some people, has a great many points in its favour, and I should be very sorry indeed to see it abandoned in this country.

The Institution in the latest revised rules has allowed certain concessions with regard to running unprotected wires in houses, but we should be very careful how we adopt it at the normal pressure used in this country. As Mr. Campion said, it appears that the "Continental wiring" is used for low voltages—that is, 100 volts or thereabouts. I do not think it will be safe in this country to use it indiscriminately

Mr. Cuttriss.

on our ordinary 200 to 250 volts pressure. This appears an important consideration, and the author remarks upon it towards the close of the paper.

Dr. Pohl.

Dr. R. POHL: No one with any knowledge of the work done by the German Institution will doubt that they have spent a great deal of time and energy and the greatest care in framing these rules, and we have reason to compare them carefully with the I.E.E. rules, and particularly to go into the question as to whether the British current density figures are really in accordance with our present knowledge and experience. In my own opinion we may practise very much higher densities without in any way running the risk of exceeding the permissible temperature rise.

This question is becoming of greater importance due to the rapid introduction of metal filament lamps. It was pointed out a few months ago that any variation in voltage has a much smaller effect on the variation in candle-power in metal filament lamps than it has in ordinary carbon filament lamps. I think a voltage variation of about 3½ per cent. in the former causes the same amount of variation in candle-power which with carbon filament lamps is caused by 2½ per cent. voltage variation. That means that in practice the temperature rise is tending more to become the limiting factor in wiring installations, and that the voltage drop is losing in importance. I should like to say that although I have no statistical figures at my disposal, I am inclined to believe the number of breakdowns in Germany is by no means higher than in England, but, on the contrary, is very much lower, although the figures for current density, as given in the German rules, are so considerably higher than the British ones. This, in my opinion, is due to another difference between the German and English rules to which the author did not allude, that is that the former rules are generally adhered to, whilst the I.E.E. rules in this country are, to my knowledge, not much more than a set of recommendations. Further, there are so many different rules, that one never knows which are to be applied in a given case. There are the Board of Trade and Home Office Regulations, Fire Insurance Rules, and those drawn up by corporations and consulting engineers. It is a deplorable state of affairs in my opinion, and something ought to be done to bring about greater uniformity.

Rules should be made not by corporations or consulting engineers, but by the nation, and they should be international as far as possible. The electrical industry is an international industry. A few years ago the German people used to export a large quantity of machinery into England, now it is almost the reverse; England is beginning to export electrical machinery into Germany and also into America. We have, therefore, to construct machines in accordance with the rules adopted in the respective countries. If they were international it would be a very great advantage to the whole of the electrical industry. That holds good not only in regard to the rules for machines, but to a great extent also to the rules on wiring installations.

There is a point of minor importance to which I wish to draw

attention. The Rules state on page 179: "In the case of advertising signs and similar installations the conductors may be proportioned for the largest value of the current consumed by the device." First of all, the words "may be proportioned" do not mean anything definite; they leave it free to the responsible contractor what size of conductor he wants to use. If it means that it must be proportioned to the maximum current I do not think that the rule is a good one, particularly in regard to advertising signs of the flicker type which are intermittent. The maximum current being only intermittent we have to apply the same rules which are applied to alternating currents, and have to work with the virtual and not the peak value of the current. Dr. Pohl.

Another point to which attention has already been drawn is the question of fuses. I think it is most important that we should consider this point. Fuses for different current strength should not be interchangeable. I think it is a common experience to see a 100-ampere fuse in a 10-ampere circuit, a fact to which many a serious breakdown is to be attributed. Everything possible should be done to guard against such mistakes.

The climate in Germany is certainly somewhat drier than that in England, still they get sometimes four or five weeks of rain, which I believe is long enough to cause the same effects on the insulation which four months of rain may cause in Bradford and Leeds, so I do not think this point of climatic difference is of great importance.

Mr. H. VISGER: The previous speakers have raised the principal points that strike one in Mr. Steinthal's interesting paper, but I would remark that the fact that the V.D.E. rules are accepted by everybody in Germany must be very satisfactory, and it would be very much more satisfactory if our own rules were treated in a similar manner. At present a contractor does not know where he is with regard to rules and regulations. When a wiring contractor in this country receives an inquiry for an installation, the first thing he asks is whether his customer has his own plant. If so he puts forward anything he considers suitable within the fire insurance company's limits, each fire insurance company, by the way, having its own rules. If the customer takes his supply from the corporation the contractor will have to deal with another set of rules. It would without doubt be a great advantage if there were one set of rules in this country made by a responsible body adopted by all concerned. Mr. Visger.

Regarding the question of fuses, as the previous speakers have said, the risks attending electrical installations are generally those of fire or to life. The voltages as used for lighting are not usually such as would under ordinary circumstances be a risk to life, but with regard to the risk of fire, the question of fuses would seem to be an important one, and I cannot agree with Mr. Cuttriss's opinion that fuses may be interchangeable. What happens, I think, in a great number of cases where fires occur is that too large a fuse has been placed in the circuit, either temporarily for some good reason and then forgotten, or simply through carelessness. The V.D.E. rules for fuses appear to prevent

Mr. Visger. larger fuses being placed in circuit, and the rule might well therefore be adopted in this country.

With regard to the question of insulation resistance of wires, I think that the insulation resistance specified for wires is frequently higher than is necessary. The way the work is carried out counts much more than the grade of wire used in many cases.

I remember once seeing some wiring which had given a great deal of trouble. The voltage of the circuit was 200, and 2,000-megohm grade wire had been specified, and the wires had been drawn into the tubes. When the wires were taken out to find the cause of the constant trouble, it transpired that the wireman had simply pulled the wire through from the coil without using a fleet, and so had pulled kinks into the tubes and rubbed the insulation off badly in places. If 600-megohm grade wire had been used and put in properly, it would no doubt have made a perfectly satisfactory job. I quote this specific instance to illustrate the meaning of my statement that the method very often counts more than the material in making a satisfactory job.

Mr. Jones. Mr. HERBERT A. JONES: There seems to be one thing, in Germany in the discussion of matters upon electro-technical subjects that they do not immediately start to quarrel among themselves, whereas in England the professional man and the manufacturer are very soon at loggerheads, and instead of a paper being dealt with in a spirit of constructive criticism we immediately get to destructive criticism. I would like to remark that I do not think this is the way we should approach the subject. It ought rather to be the other way, and our desire should be to promote the best interests of the profession rather than to weaken our own position by somewhat unfair criticism.

There are various points in the paper which are utterly foreign to our practice. The employment of bare conductors in breweries, dye-houses, etc., has been condemned, although this is a common practice on the Continent. Personally I do not see any reason why, for a low-voltage circuit, bare conductors on insulators should not be allowed inside a building.

One point in German practice I notice which is being introduced in this country, is that of insulators of battery stands. Although it has been the practice always to insulate each cell from the stands upon which the cells are placed, yet it is undoubtedly a still better practice to insulate the stands as well.

I fully agree with the idea of marking the current-carrying capacity of switches and plug sockets, but I would suggest that they should also be marked for the voltage that they are capable of working at, as undoubtedly there are some switches on the market, which, while being quite good and substantial switches where the voltage does not exceed 230 volts direct current, are absolutely useless on 440 or 500-volt circuits.

Mr. Dickinson. Mr. H. DICKINSON: The only point I wish to raise is regarding the size of the conductors. I am inclined to think that the size we allow is too small. There is no doubt that there are many cases where

the current density is very much above the limit that the rules allow, as we often come across such cases in Leeds. The wires are put in all right in the first place, but extensions are put on, which make a considerable difference. The mains are sometimes found to be very much overloaded, but we have no trouble except that due to drop of pressure. Mr. Dickinson.

In damp places, etc., special regulations ought to be made, but I certainly think we could allow a larger amount with perfect safety under ordinary conditions.

Respecting the dielectric, I am of opinion that the stipulation as to thickness ought to be kept up. If we consider a number of old installations that were put in many years ago, it will be found in many cases that the rubber has perished, and it would not be allowed to be put in again as it would not pass the rules to-day. At the same time we should not refuse an installation of that sort. We should not think of making a person relay it, except in a very bad case. I think it better to keep up the thickness, because if the covering on the cable is very thin, and it does perish, the position will be worse than with the thick covering.

In cases of old installations we make a special point of the fusing, and wherever there is a change in section a fuse is put in, and I think that if proper attention is paid to this matter ample safety is provided for.

Mr. I. F. FAWCETT: In paragraph XX., clause 2, of the Rules it is said that for intermittent work a higher current density is permissible than that given in the table so long as there is no undue heating beyond what would take place with the current density given in that table. It would be interesting to know if this refers to power loads and can be regarded as a time rating for cables. Mr. Fawcett.

It appears that the thickness of the dielectric for cables is less than the dielectric for cables in this country, and I should like to know if this is the case in actual practice. We find in selling cable that the German cable sent over here sells cheaper in this market, and although the cable is not always good, I think it will be of the same grade. The author points out that there is no rule that recommends that rubber should be put against the conductor in a cable, but I remember buying a quantity of German cable some years ago and found when stripping it that there was a rubber insulation inside the cable, but I do not know whether it is the practice over there, or whether this is only done with cable sent here.

I quite agree with others that there can be nothing more absurd than to find a country like England possessing so many different sets of rules.

The only thing I can suggest is that the Government should pass an Act and make the Institution rules compulsory, and then the contractor would have a chance of knowing what he was doing.

Mr. STEINTHAL (*in reply*): The Germans, up till very recently, have been in the habit of using the so-called "Continental flexible wiring," which was used when no installation probably exceeded 125 volts. There are a great many places now where they are contemplating going on Mr. Steinthal.

Mr. Steinthal.

to the higher pressure (250 volts), and in these cases they invariably use papier-mâché tubing. There are very few cases in Germany where wood-casing is used. I am inclined to agree with Dr. Pohl as to current density in so far that I am perfectly satisfied that the German engineers know very well what they are talking about, and they do not make regulations which are not the result of very careful investigation. The general opinion is that we are rather inclined to use an unnecessary amount of copper in various installations.

I agree with Mr. Cuttriss's observations regarding the marking of switches, but at the same time I think it is the fault of the manufacturers to a great extent. We have a standardised 5-ampere switch carrying 20 lamps, but I have seen it used for a 2½-c.p. lamp.

The remarks made by Mr. Campion regarding the contact of inflammable material with incandescent lamps are certainly very true. I think that the danger will be obviated to some extent by the new incandescent lamps which undoubtedly burn very much cooler than the old ones.

The question of interchangeability is of very great importance. At present we have an ordinary porcelain fuse with a screw terminal at either end, and our wiremen, if they do not happen to have the proper size of wire, will use anything—sizes are not of importance, so long as there is a piece of fuse wire from one end to the other. With the Edison pattern the plug is of a certain diameter and of a certain length and cannot be screwed into a wrong socket. If a wrong plug is screwed into position it will not make contact because it is too short, and in the German rules a standard size is laid down for these plugs both as regards length and diameter.

Dr. Pohl referred to a paragraph where the word "may" occurs. I have not had an opportunity of referring to the German edition again, but I believe the translation is correct. I would point out that this occurs in a paragraph which is headed by a number, and these are merely recommendations and not regulations.

With regard to general current density used for cables, mention has been made respecting the short-time rating for these particular densities, but I do not think that this is the case. A reference to the table on page 175 will show that insulated copper conductors not laid underground must not be loaded for any length of time beyond the current density given in the table, from which I take it that for short-time rating—that is, for intermittent work—the conductors may be loaded to a greater extent than that given in the table.

I am entirely in agreement with Mr. Dickinson as to the thickness of insulation, but with regard to what Mr. Cuttriss said as to the inferior insulation, the insulation being a little thinner does not necessarily mean that the material employed is inferior. It is a curious thing that right through the German rules I can find no reference to pure rubber used in conjunction with vulcanised rubber. The pure rubber, it will be found, is only allowed in the case of installations which do not exceed 125 volts. There is no reference to any pure rubber in

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installations of higher pressure. We hear a good deal about foreign cable, and a great many engineers are inclined to turn up their noses at what is called "foreign cable"; but I want to point out that most German engineers and manufacturers are far too cute business men to send over here the thin cable which passes their rules as they know it is of no use. They make cable to what they call the English specification. It may be that some of it is of inferior quality, but some of it looks very good. The Germans seem to use only vulcanised rubber for flexibles on circuits over 125 volts. I had the opportunity the other day of inspecting a flexible sent to me which was in conformity with the requirements of the Leeds Corporation. This was double rubber, and I had previously asked that particular care should be taken that they sent me one which had passed the Leeds Corporation test. I am glad to see that we are well protected by such a concern as the Leeds Corporation in insisting on the proper quality. If there were one set of rules to which all engineers ought to work, as they do in Germany, I am perfectly certain that we should be saved a lot of trouble and get rid of a great deal of inferior material.

As Mr. Visger said, when a private plant is concerned where there is no control whatever, other than the control of the insurance company, one never knows exactly what may be done, and the control of the insurance company is by no means efficient. In a large number of cases the inspection by the insurance company consists in the posting of a copy of their regulations with about 250 questions which have to be answered. I have known them sent back with about five questions answered, and I suppose they have passed them. I do not rely very much on the insurance company, except in those cases where there is an actual contract with them for upkeep, and then they look well after it.

ORIGINAL COMMUNICATION.

THE POTENTIAL OF PARTIALLY INSULATED SYSTEMS IN RELATION TO THE POTENTIAL OF EARTH.

By M. B. FIELD, Member.

(*Chairman of Manchester Local Section.*)

(*Received January* 8, 1908.)

The provision of efficient insulation for any electric circuit necessitates some knowledge of the difference of potential existing between portions of the circuit in proximity to one another, and also the potential of each several part in relation to that of earth.

If the information available with regard to the internally generated E.M.F.'s be sufficient for the determination of the differences of potential obtaining between different points of the system, and if we can arrive at the potential of any one point in relation to that of earth, obviously the potential of any other point in relation to that of earth may be immediately deduced.

The first question to be answered, in order to determine the potential of any point to earth, is whether the system as a whole has acquired a charge of electricity from some external source. A system comprising a generator and an external circuit may become charged as a whole in several ways; for example, if it include overhead transmission lines it may become charged as a result of atmospheric disturbances.

In such a case the conductors of the system in conjunction with the earth perform the function of the metallic plates or coatings of a condenser, while the general insulation of the system behaves as the dielectric of the same. Should the system become charged in this way, a potential differing from that of earth is necessitated, the potential difference being equal to Q/K, where Q is the quantity of electricity stored and K the capacity of the system to earth.

A charge of this nature must be regarded as constituting a temporary and abnormal condition, since the charge will be rapidly dissipated by leakage to earth.

It might at first sight appear that the possible abnormal potential differences should form the governing feature in determining the nature of the insulation of the system, as they may be many times greater than any internally generated E.M.F. This, however, is not necessarily the case—first, because it is possible to connect apparatus to the system to limit the rise of potential occurring during the abnormal condition; and secondly, on account of the extremely short duration of the same.

Insulation appears to break down under electric stress either by mechanical rupture alone or by mechanical rupture in conjunction with gradual local deterioration, accompanied by local heating and sometimes charring.

What *rôle* the duration of the applied stress plays in the first case it is difficult to say, but it is certain that where the breakdown is accompanied by heating the duration of the applied stress is one governing

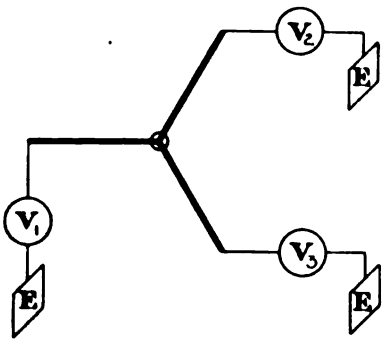


FIG. 1.

feature. Thus a slab of insulating material may successfully withstand a difference of potential of 20,000 volts if applied for but one-fiftieth of a second, and break down under a potential difference of 2,000 volts if applied continuously.

The question, therefore, of the potential in relation to that of earth that any part of the system may be called upon to withstand for a sustained period, is of great importance.

It will be convenient to take the potential of earth as a datum or zero of reference, so that we may speak of the actual potential of any point of a system, instead of the difference of potential existing between that point and earth.

If the system be charged as a whole, the potential may temporarily have any value depending upon the amount of the charge, but as this transient condition subsides each point of the system assumes a certain potential, which may be constant or variable according to the nature of the internal E.M.F.'s.

Thus if we connect an electrostatic voltmeter between each terminal of a 3-phase system and earth, as in Fig. 1, we find that each voltmeter

indicates a definite potential difference. Unless some point of the system be directly connected to earth there is no reason why any point should be permanently at earth or zero potential. If, however, a 3-phase system be perfectly balanced, both as regards load and leakage currents, it frequently occurs that the neutral point o in Fig. 1 is at earth potential. It must, however, be remembered that this is by no means *necessarily* the case; indeed, it also frequently happens that although the system be symmetrical and perfectly balanced, so that the voltmeter readings V_1, V_2, V_3 are identical, there is a considerable potential difference between the neutral-point and earth.

Opinion is divided among electrical engineers as to the advisability of connecting the neutral-point of a 3-phase system to earth, and thus ensuring that it shall remain at earth potential, but when this is not done, electrostatic voltmeters are usually connected between each terminal and earth as shown in Fig. 1 to indicate any disturbance of the natural distribution of potential. In such cases the readings of the voltmeters will be affected if any one of the terminals becomes partially or totally earthed, and it is frequently assumed that such a voltmeter combination forms a fairly sensitive indicator of the relative insulation resistance of the three terminals of the system taken together with the line wires and other portions connected thereto. If, however, the generator system be connected to a cable network of considerable dimensions, the natural capacity current flowing from each terminal to earth may be so largely in excess of the current leaking through the insulation resistance as to entirely mask any effect which a considerable want of balance of the latter may tend to produce. In such instances the 3-voltmeter combination forms an extremely insensitive indicator of relative insulation, but correctives may be introduced to materially increase the sensitiveness of the device.

The object of this communication is to discuss the various points raised above, on the assumption that all electrostatic charges are due to the internally generated E.M.F.'s, and consequently that the system is not in the abnormal condition referred to above.

It will be appreciated that this subject has a distinct bearing upon the regulation recently issued by the Home Office enforcing the employment of leakage detectors in connection with electrical installations in mines.

If we assume that the generated E.M.F.'s follow sine laws, the subject may be treated in an extremely simple non-mathematical manner. The first portion of this communication will therefore deal with the matter from this point of view, and in the Appendix will be found a general proof of the theorems employed, not involving any assumptions as to the law of variation of the generated E.M.F.'s.

Current may leak to earth from any part of a system through—

(1) The insulation resistance of that part of the system,
(2) The capacity to earth.

In direct-current systems we have only to consider (1), but in alternating-current systems a capacity current is always flowing to earth from all parts of the system, and in the case of extra high-tension generators and cable networks, the capacity current through the insulation of the winding and the dielectric of the cable may be considerable.

Inductive leakage paths do not naturally occur, but they may sometimes be considered since their presence may be beneficial, and they may be introduced artificially.

If r be the insulation resistance of any portion of a system, and v the potential, the value of the leakage current to earth is v/r.

If, however, this portion of the system be connected to earth through a capacity k, the leakage current will be $k\frac{dv}{dt}$, or $k\theta v$, where θ stands for the operator d/dt; or if it be grounded through the inductance l the leakage current will be $\frac{v}{l\theta}$.

If from a given point of a system there be three leakage paths comprising respectively a resistance r, a capacity k, and an inductance l, the total leakage current will be—

$$\left(\frac{1}{r} + k\theta + \frac{1}{l\theta}\right)v \quad \ldots\ldots\ldots \quad (1)$$

The expression $\left(\frac{1}{r} + k\theta + \frac{1}{l\theta}\right)$, or its equivalent, is an operator, which when operating upon the potential v (expressed as a function of the time) gives leakage current. Although this expression involves the physical constants of the combination of leakage paths, it cannot of itself be considered as a physical constant, since it also involves the idea of time-variation. When, therefore, we define a leakage path (or combination of leakage paths) by means of the physical constants as $\left[\frac{1}{r}, k, \frac{1}{l}\right]$, we shall imply a path equivalent to one containing a resistance r, in parallel with one containing a capacity k, in parallel with one containing an inductance l, the total leakage current through such a path being represented by the expression (1).*

Since the operator θ applied to the function $\sin pt$ gives $-p^2$ times the result of applying the inverse operation $\left(\frac{1}{\theta}\right)$ to the same function,

* In view of the small values of dielectric hysteresis of the materials employed for insulating cables, generator, and transformer windings, etc., the current flowing to earth by such paths may here be taken as a true capacity current. Similarly when a fault develops in a system it may be considered as a true ohmic resistance. It is difficult to imagine a case of current leaking to earth through a path containing, say, a resistance and a capacity in series. Later on an instance is considered where inductive paths are introduced; in such a case we must have a certain amount of resistance in series with the inductance. In what follows, however, it will be seen that we are justified in considering a capacity current flowing to earth through a path containing capacity only, a further conductance current flowing to earth through a path containing ohmic resistance only.

the term $\frac{I}{l\theta}$ may be replaced by the term $k'\theta$, where $k' = -\frac{I}{lp^2}$. Terms such as $\frac{I}{l\theta}$ may therefore be considered as included in terms such as $k\theta$, so that it will be unnecessary to express the former separately.

If a system have distributed leakage paths represented in terms of the convention, already explained, as $\left[\frac{I}{r_1}, k_1\right]$, $\left[\frac{I}{r_2}, k_2\right]$, $\left[\frac{I}{r_3}, k_3\right]$, etc., we shall refer to $\frac{I}{r_1} + \frac{I}{r_2} + \frac{I}{r_3} +$, etc., as the "total leakage conductance," and to $k_1 + k_2 + k_3 +$ etc., as the "total leakage capacity."

It will be noticed that the total leakage conductance is merely the reciprocal of the insulation resistance of the whole system, while the

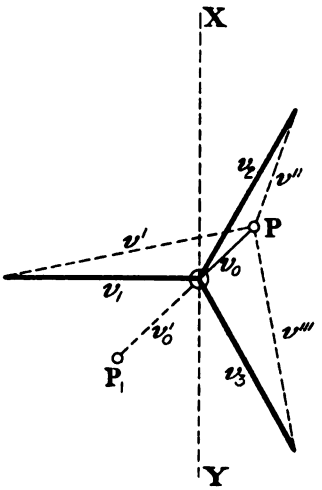


FIG. 2.

total leakage capacity is the capacity to earth of the whole system. Those points of a system where leakage is supposed to occur will be hereafter referred to as the "leakage points."

Provided the E.M.F.'s generated in each portion of an interconnected system be sinusoidal, we may represent them on a clock diagram in the well-known way. For example, in Fig. 2 the vectors v_1, v_2, v_3 represent the E.M.F.'s induced in the three windings of a 3-phase Y-generator. We may either suppose that v_1, v_2, and v_3 are vectors which by their length and position represent the amplitude and phase of the E.M.F.'s induced in the three windings; or, if we wish to consider the instantaneous values of these E.M.F.'s, we may confine our attention to the projections of the vectors on the vertical axis X Y.

As has been stated, unless some point be directly connected to earth, there is no reason why *any* point should be at earth potential;

we can, however, always find a point on the diagram representing zero potential. To make the meaning of this clear, let P be this point. Then adopting the interpretation indicated above, the vectors v', v'', and v''' must represent the amplitude and phase, and their projections the instantaneous values of the potential of the three terminals of the system. Similarly the vector v_0 represents the potential of the neutral-point.

Further, we see that any point such as P_1 represents some definite potential in relation to that of any point of the system, varying according to a sine law. If, however, P_1 does not correspond to any point or part of the generative system, but to some external point which is not connected to earth, this conception at first sight appears somewhat

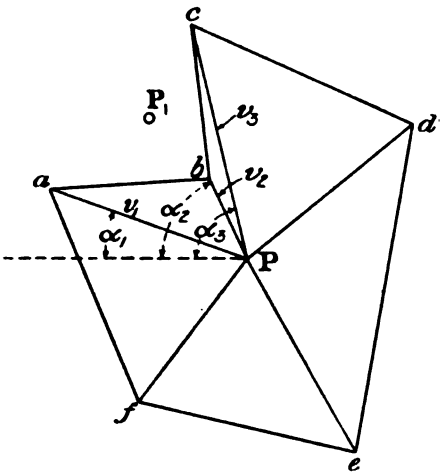


FIG. 3.

vague. The diagram tells us, however, that the potential of the point P_1 is related to that of the point o by the vector v_0', and the vagueness at once disappears if we assume an imaginary winding connected to the point o in which an E.M.F. is induced corresponding to the vector v_0'. Thus the point P_1 at once becomes bound to, and a point on, the generative system.

If we know the laws which the internally generated E.M.F.'s follow and we can determine v_0, that is the vector which binds the point of zero potential to the neutral-point, we know the potential of every point of the system.

The condition which determines v_0 is that the total leakage current flowing to earth is zero at every instant.

Let us consider a complex system with leakage points at a, b, c, d, e, f, and zero potential at P. Let v_1, v_2, v_3, etc., Fig. 3, be vectors repre-

senting the potentials of the leakage points, and let the time variation of the potential of a be $v_1 \sin(pt + a_1)$.

The time variation of the potential at the other leakage points will then be—

$$v_2 \sin(pt + a_2)$$
$$v_3 \sin(pt + a_3), \text{ etc.}$$

Let the leakage conductance at the points a, b, c, etc., be respectively $\frac{1}{r_1}$, $\frac{1}{r_2}$, $\frac{1}{r_3}$, etc., then the total current leaking to earth is—

$$\frac{v_1}{r_1}\sin(pt + a_1) + \frac{v_2}{r_2}\sin(pt + a_2) + \frac{v_3}{r_3}\sin(pt + a_3) + \text{etc.},$$

this current is zero at every instance, hence, inserting the values $pt = 0$, $pt = \frac{\pi}{2}$ we obtain the two independent equations—

$$\left.\begin{aligned} \frac{v_1}{r_1}\sin a_1 + \frac{v_2}{r_2}\sin a_2 + \frac{v_3}{r_3}\sin a_3 + \text{etc.} = 0 \\ \frac{v_1}{r_1}\cos a_1 + \frac{v_2}{r_2}\cos a_2 + \frac{v_3}{r_3}\cos a_3 + \text{etc.} = 0 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

If, however, we had concentrated at the points a, b, c, etc., on the diagram masses proportional to $\frac{1}{r_1}$, $\frac{1}{r_2}$, $\frac{1}{r_3}$, etc., respectively, the equations (2) are those which would determine the position of the centre of gravity of the system. We may therefore say that the point on the diagram representing zero potential occupies the position of the centre of gravity of a number of masses located at the leakage points proportional respectively to the value of the corresponding conductance.

Further, the centre of gravity of any given group of masses has an important analogue in the electrical case. Consider the points a, b, c, connected to earth by leakage paths $\left[\frac{1}{r_1}\right]$, $\left[\frac{1}{r_2}\right]$, $\left[\frac{1}{r_3}\right]$, etc.

Suppose for a moment a resistance r_1 connected to the system at a, a resistance r_2 connected at b, and r_3 at c, and imagine the other ends of these resistances all connected together in a bunch at a point P_1. Obviously, the total current flowing towards P_1 at every instant is zero, and P_1 will have a definite potential in relation to that of a, b, etc. That is to say, the potential of P_1 may be represented by a point on the diagram suitably situated with reference to the points a, b, and c. This point we call the Z-point due to the particular leakage paths under consideration (the leakage current from the poles to such a point being zero, as explained) ; it obviously corresponds to the centre of gravity of the masses representing these leakage conductances. The Z-point has no direct relation to earth or zero potential, unless, indeed, all the leakage paths of the system are fixed, but a Z-point can only be deter-

mined in relation to some particular group of leakage paths. The zero potential-point is, of course, the Z-point of all the leakage paths of the system.

The principle of the equivalent masses at once indicates that if the zero potential-point be caused to deviate from P by the introduction of additional leakage paths, the deviation may be calculated as though the only leakage paths existing were the *additional* leakage paths together with a single leakage path $\left[\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\text{etc.}\right]$ concentrated at the point P.

Had we assumed a combination of capacity or of inductive leakage paths in place of the combination of conductance paths, we should have seen that the zero potential-point similarly corresponded to the centre of gravity of proportional masses suitably placed on the diagram.

We must now consider how conductance, capacity, and inductive leakage paths may be combined.

Consider first the combination of a capacity and a conductance leakage path in a system comprising two leakage points.

Let, in Fig. 4, the point a be connected to earth by the capacity k, and the point b by the conductance $\frac{1}{r}$. It will be seen that the locus of the Z-point P (and in this case the zero potential-point) is a semicircle of which $a\,b$ is the diameter. a P represents the E.M.F., which, acting through the capacity k, gives rise to a current at right angles to itself. This current must be equal and opposite to the current due to the E.M.F., b P acting through the conductance $\frac{1}{r}$. Hence a P b is a right angle and the locus of P a semicircle.

We have the numerical relation—

$$a\,\mathrm{P} \times k p = b\,\mathrm{P} \times \frac{1}{r},$$

or—

$$\frac{a\,\mathrm{P}}{b\,\mathrm{P}} = \frac{1}{k p r}.$$

If we drop a perpendicular from P meeting $a\,b$ in c, we have—

$$\frac{a\,c}{c\,b} = \left(\frac{1}{k p r}\right)^2 \quad \ldots\ldots\ldots\ldots \quad (3)$$

Hence, knowing k, p, and r, we can readily determine the position of the Z-point.

We thus see that a capacity cannot be directly combined with a conductance in the same manner in which two conductances or two capacities may be combined, but that the line joining the points on the diagram at which a capacity and a conductance are situated respectively, in passing through the Z-point is bent at right angles at this point. The combination of an inductance and a conductance is given by the same construction, only the semicircle must be drawn upon the opposite side of $a\,b$.

We will next consider the combination of a capacity and inductance. At point a, Fig. 5, assume a capacity k, and at point b an inductance l. Then a little consideration will suffice to show that the Z-point P will lie on $a\,b$ produced, but it cannot lie between a and b.

If $k\,l\,p^2 < 1$ the Z-point will occupy a position as at P_1; as $k\,l\,p^2$ approaches unity the Z-point will recede along $a\,b$ (produced) to infinity; as $k\,l\,p^2$ still further increases, the Z-point will advance from infinity on the lower side towards a.

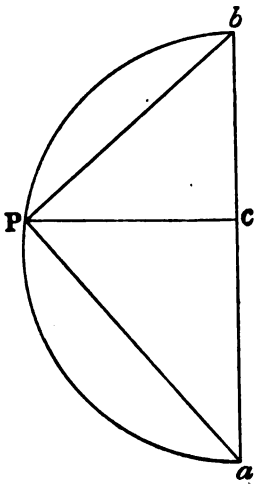


FIG. 4.



FIG. 5.

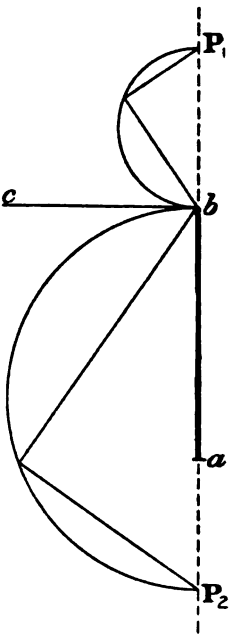


FIG. 6.

Let, now, a conductance $\frac{1}{r}$ be introduced at b in addition to the inductance. If $k\,l\,p^2 \gtrless 1$, the capacity and the inductance may be combined, and the resulting Z-point found as above described. The conductance $\frac{1}{r}$ at b may now be added, and the new Z-point determined by the semicircle construction, as in Fig. 4. In Fig. 6 two cases are shown where the capacity predominates and where the inductance predominates. It will be observed that, if correctly drawn, both semicircles lie on the same side of $a\,b$ produced. Now, as $k\,l\,p^2$ approaches unity, the points P_1, P_2 respectively recede to infinity, and at the limit $b\,c$ will form an arc of both semicircles. Therefore, when $k\,l\,p^2 = 1$, the locus of the Z-point is $b\,c$. If $\frac{1}{r} = \infty$

the Z-point is at b, as $\frac{I}{r}$ is reduced to zero, the Z-point recedes along $b\,c$ to infinity.

It is interesting to observe that we have approached the condition of a capacity and inductance where $k\,l\,p^2 = 1$ from three points of view, resulting in the Z-point being at infinity along $a\,b$ produced; at infinity along $b\,a$ produced; and at infinity along $b\,c$ produced. But two or more points on the diagram cannot represent the same potential since this would be contrary to the convention upon which the diagram is based.

Consideration of the principle of equivalent masses and the position of the centre of gravity in relation thereto at once leads us to the following conclusions :—

1. That the position of a Z-point and of the point of zero potential depend upon the relative, and not upon the absolute, values of the leakage constants.

2. If $\frac{I}{R}$ be the total conductance of a number of conductance leakage paths whose Z-point is at P_1 and K, the total capacity of a number of paths whose Z-point is at P_2, the Z-point of the whole system may be determined as if there were merely a single path $\left[\frac{I}{R}\right]$ at P_1 and a single path [K] at P_2.

3. In the system postulated in 2, let P be the resultant Z-point (obtained by joining P_1, P_2 and applying the semicircle construction). If, now, additional paths be introduced, the position of the zero potential-point may be determined as if the only existing leakage paths were the additional ones, and a single path $\left[\frac{I}{R}, K\right]$ at P.

4. If the position of the Z-point due to a combination of leakage paths of total conductance $\frac{I}{R}$ and total capacity K be at P_1, and the position of the Z-point due to another combination of total conductance $\frac{I}{R'}$, and total capacity K' be at P_2, then if both combinations be present simultaneously the position of zero potential may be calculated as though the only paths existing were those represented by $\left[\frac{I}{R}, K\right]$ at P_1 and $\left[\frac{I}{R'}, K'\right]$ at P_2.

5. For the determination of the point of zero potential we may replace any combination of leakage paths by any other combination of the same total capacity and conductance giving the same Z-point.

We will now apply some of the results obtained above.

The analogy between the position of the centre of gravity of a number of masses and that of the point of zero potential due to a combination of leakage paths shows us that if current leak to earth

from the three terminals of a 3-phase system, and the leakage paths comprise only conductances, or capacities, or inductances, the zero potential-point must lie within the triangle, Fig. 7. It can only lie on the boundary if the leakage current from the opposite terminal is zero. If some of the leakage paths comprise conductance and some capacity, or if some comprise conductance and some inductance, the zero potential-point must lie on or within the curved boundary made up of the three semicircles as in Fig. 7. In this case we may have a potential such as c P, greater than any E.M.F. generated within the system.

It is interesting to note in this connection that if we have a capacity at a, and a conductance at b such that $kp = \frac{I}{r}$ the zero potential-point will be at P with one direction of rotation, and at P_1 with the opposite rotation of the generator. Thus we see that the maximum potential may depend on the sense of rotation of the generator system. This is an instance exemplifying the dissymmetry of a 3-phase system depending on phase rotation.

If we have a combination of conductance, capacity, and inductance paths the zero potential-point may lie anywhere, and may, in fact, be at infinity. This is, of course, a case of partial or complete resonance.

The case previously considered of capacity in combination with conductance is not unlike partial resonance.

On the other hand, where the boundary involves a re-entrant angle as a, b, c in Fig. 3, the zero potential-point may lie external to the boundary, *e.g.*, as at P_1, Fig. 3.

In a given 3-phase system leakage conductances $\frac{I}{r_1}, \frac{I}{r_2}, \frac{I}{r_3}$ occur at the terminals a, b, c. Suppose $\frac{I}{r_1}$ to be the smallest of these.

We may then consider that we have two combinations of conductances, namely, a conductance $\frac{I}{r_1}$ at each pole, and also conductances o, $\left[\frac{I}{r} - \frac{I}{r_1}\right]$ and $\left[\frac{I}{r_3} - \frac{I}{r_1}\right]$ at the three poles respectively. For the first combination the Z-point is at the neutral-point o; taking the second combination by itself, the Z-point lies on the line $b\,c$ at, say, P_1, Fig. 8. The whole combination is therefore equivalent to a conductance $\frac{3}{r_1}$ at o, together with a conductance $\left[\frac{I}{r_2} + \frac{I}{r_3} - \frac{2}{r_1}\right]$ at P_1. The resultant Z-point, or zero potential-point, is readily found, and lies on o P_1 at, say, P_2. Now, superpose a capacity k at each pole, the equivalent system is given by a capacity of $3k$ at o, and a conductance of $\left[\frac{I}{r_1} + \frac{I}{r_2} + \frac{I}{r_3}\right]$ at P_2.

It will be seen how simple the determination of the position of the zero potential-point has become.

At first sight it would appear that the problem would be complicated

by the existence of internal leakage paths in the generative system. The complication, however, disappears as soon as we localise these paths at the experimentally determined Z-point.

Thus, if we measure R the total insulation resistance, and K the total capacity, and determine the position of the Z-point by voltmeter readings to be at, say, P_1, we may consider the total distributed leakage paths to be replaced by a single leakage path denoted by $\left[\frac{1}{R}, K\right]$ at P_1.

The effect of equal capacities at the poles (as when a cable network is connected) in rendering the potential of the neutral-point more stable is very obvious.

Suppose in Fig. 8, *a* and *c* to be perfectly insulated and that at *b* a very small conductance leakage path exists. However small this con-

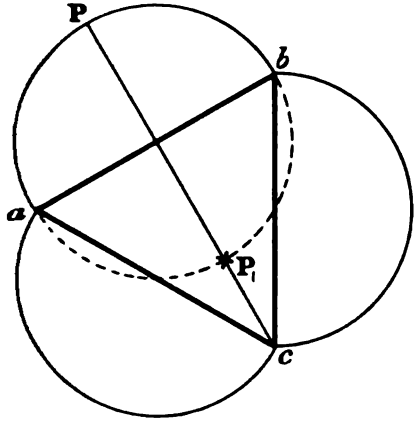


FIG. 7.

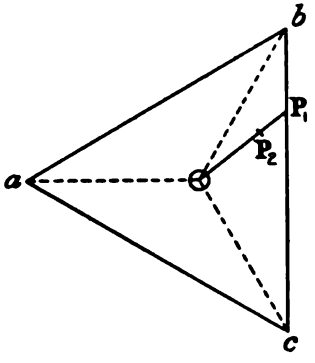


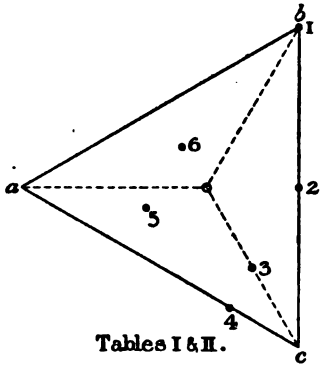
FIG. 8.

ductance may be the zero potential-point will be at *b*. Now introduce at *a*, *b*, and *c* a capacity *k*, or the equivalent of $3k$ at o. If $3kp$ be large in comparison with $\frac{1}{r}$ (the conductance) the effect of capacity will be to move the zero potential-point from *b* to the immediate neighbourhood of o, by a semicircular path.

A similar result would be obtained if o were connected to earth by a moderately high resistance, but considerably lower than *r*, only in this case the zero potential-point would travel along o *b* towards o.

Now, if it be desirable to render the electrostatic voltmeter arrangement a sensitive relative insulation indicator, the capacity must be neutralised by the introduction of inductances.

For this purpose each 3-core cable would have a 3-phase inductance connected permanently between each core and earth, so that for



Tables I & II.

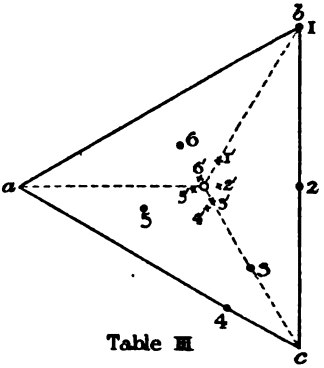
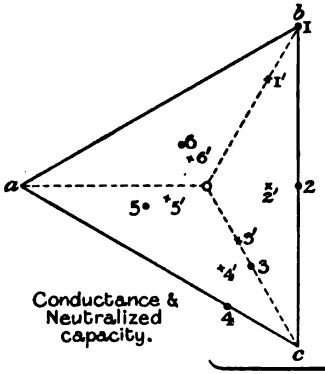
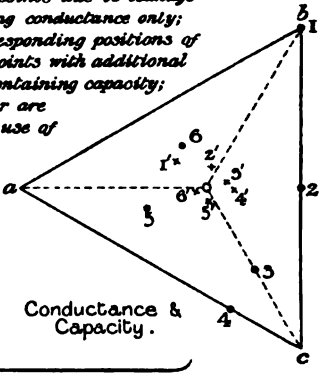


Table III

Points marked 1,2,3....6 are positions of zero-potential-points due to leakage paths containing conductance only; 1',2'....6' are corresponding positions of zero-potential-points with additional leakage paths containing capacity; also, when latter are neutralised by use of choking coils.

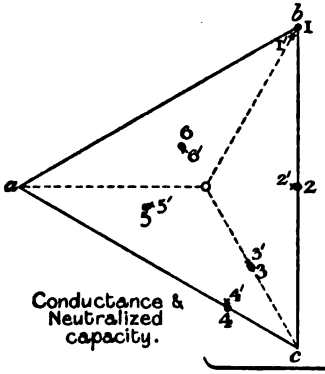


Conductance & Neutralized capacity.

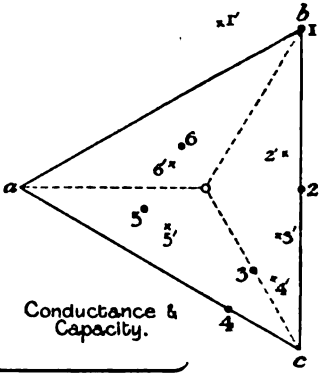


Conductance & Capacity.

Table IV.



Conductance & Neutralized capacity.



Conductance & Capacity.

Table V.

FIG. 9.

the particular frequency the capacity of the system would be always neutralised no matter how many cables were in use. If the generator windings had appreciable capacity this again would need neutralising. Tappings might be taken from the windings of the choking coils to which low-tension electrostatic voltmeters were connected, thus avoiding the use of high-tension voltmeters altogether. The choking coils connected to the generators might possibly be further used for synchronising and other purposes.

It may be considered that anything which tends to render the potential of the neutral-point stable is advantageous, and that the capacity effect is therefore beneficial. If this view be adopted, and, as previously stated, considerable difference of opinion exists among engineers, surely the simplest manner of achieving this result would be to connect the neutral-point to earth through a suitable resistance. By this means the potential of the neutral-point may be rendered as stable as may be desired. It must, however, be remembered that unless the neutral-point be *directly* connected to earth, a total earth at any terminal must raise the potential of the neutral-point and the other terminals to the same extent as if the neutral-point were insulated, unless, indeed, considerable internal drop of pressure occur in the generator system.

It is not practically possible to perfectly neutralise a capacity effect, because inductances cannot be constructed in which the current lags 90° behind the E.M.F.

Probably inductances could be made of the size required for this purpose in which the loss did not exceed 2 per cent. of the apparent power, but in order to exemplify the effect of imperfect inductances, let us assume that 84° is the practicable limit, then it is clear that when we neutralise the capacity K at a point, we introduce the equivalent of a conductance at the same point whose value is—

$$K p \tan 6^\circ (= 0{\cdot}1\ K p).$$

It is perhaps as well to point out that in the imperfect inductance we have a combination of inductance and resistance in series, whereas we are replacing this by a combination of inductance and resistance in parallel giving the same power factor. Such a substitution can only be valid for a system where the frequency is constant. Further, the capacity effect is only neutralised by a given inductance at one particular frequency.

In Fig. 9 we represent the position of the zero potential-point in a 3-phase system: (1) With various insulation resistances at the poles; (2) with a capacity of 5·3 microfarads between each pole and earth (a figure undoubtedly surpassed in many systems in this country); (3) with this capacity effect neutralised by inductances of which the lag angle is 84°. Frequency assumed 50 ∿.

Fig. 9 is to be read in conjunction with the following table :—

	Insulation Resistance of Poles.			Position of Zero Potential-point in Diagram.		
	a.	*b.*	*c.*	With Conductance only.	With Capacity.	With Capacity Neutralised.
Table I. Total Insulation Resistance = 1 meg.	Meg. Inf.	Meg. 1·0	Meg. Inf.	1	Zero Potential-point indistinguishable from neutral-point.	Ditto.
	Inf.	2·0	2·00	2		
	6·000	6·0	1·50	3		
	4·000	Inf.	1·33	4		
	1·846	6·0	3·43	5		
	2·400	2·4	6·00	6		
Table II. Total Insulation Resistance = 100,000 ohms.	Ohms. Inf.	Ohms. 100,000	Ohms. Inf.	1	Indistinguishable from neutral-point.	Lies within circle drawn round neutral-point.
	Inf.	200,000	200,000	2		
	600,000	600,000	150,000	3		
	400,000	Inf.	133,000	4		
	184,600	600,000	343,000	5		
	240,000	240,000	600,000	6		
Table III. Total Insulation Resistance = 10,000 ohms.	Inf.	10,000	Inf.	1	Lies within circle drawn round neutral-point.	1′
	Inf.	20,000	20,000	2		2′
	60,000	60,000	15,000	3		3′
	40,000	Inf.	13,300	4		4′
	18,460	60,000	34,300	5		5′
	24,000	24,000	60,000	6		6′
Table IV. Total Insulation Resistance = 1,000 ohms.	Inf.	1,000	Inf.	1	1′	1′
	Inf.	2,000	2,000	2	2′	2′
	6,000	6,000	1,500	3	3′	3′
	4,000	Inf.	1,330	4	4′	4′
	1,846	6,000	3,430	5	5′	5′
	2,400	2,400	6,000	6	6′	6′
					Right-hand diagram.	Left-hand diagram.
Table V. Total Insulation Resistance = 100 ohms.	Inf.	100	Inf.	1	1′	1′
	Inf.	200	200	2	2′	2′
	600	600	150	3	3′	3′
	400	Inf.	133	4	4′	4′
	184	600	343	5	5′	5′
	240	240	600	6	6′	6′
					Right-hand diagram.	Left-hand diagram.

It will be noticed that if the insulation of each pole is 1 megohm or more, the effect of the capacity, whether neutralised or not, is to render the neutral-point quite stable.

If the minimum insulation of a pole be 100,000 ohms, the zero potential-point just begins to deviate from the neutral-point if the capacity be neutralised.

If the minimum resistance of a pole be 10,000 ohms the deviation of the zero potential-point is marked if the capacity be neutralised, but scarcely measurable if this be not the case.

With a minimum insulation resistance of 1,000 ohms the deviation of the zero potential-point with the capacity neutralised is great. Without this neutralising effect, however, the deviation, though quite measurable, is not great.

When the minimum insulation resistance per pole is of the order of 100 ohms the zero potential-point is quite unstable; it will be noticed that it may fall outside the triangle altogether, see Fig. 9 (bottom right-hand diagram).

If we assume a smaller loss in the inductances, their neutralising effect will be greater. It should thus be possible to render the electrostatic device very fairly sensitive.

In an extra high-tension system such as we have been considering, it is hardly conceivable that a fault measuring 1,000 ohms can develop without almost immediately becoming a total earth, since the heat generated in such a fault would be very great indeed. Suppose, for example, that the insulation resistance of one pole be 1,000 ohms, and the insulation resistance of the other two poles be infinity, the effect of the capacity of the system would be such as to maintain, to a considerable extent, the potential of the defective pole. If the voltage between phases be, say, 6,500, then, with the constant above assumed, the potential to earth of the defective pole would be of the order of 3,700 volts (see diagram corresponding to Table IV.). It follows that heat would be generated at the fault to the extent of 13 k.w., which would obviously be sufficient to rapidly burn out the remaining insulation.

Several engineers in charge of extensive high-tension systems have called attention to the fact that when a fault develops on a cable a very little time elapses, as a rule, between the moment when a disturbance of the electrostatic voltmeters is first detected, and the development of the fault into a dead earth, a time frequently insufficient for the localisation and interruption of the faulty feeder. In the light of the above calculations, the reason for this is fairly obvious, and this, at least, is an argument in favour of neutralising the capacity effect, as far as possible, and thus rendering the electrostatic voltmeter combination more sensitive. We also see that keeping the neutral-point of an extensive system unearthed is absolutely no safeguard against shock to a human being should he come in contact with one pole. The capacity effect is such as to render the earth-point stable, so that he would receive very nearly the full voltage across his body, producing a corresponding current. There can be no safeguard whatsoever in keeping the neutral-point unearthed. It is also doubtful whether neutralising the capacity in the manner suggested would prove sufficient safeguard: first, because, as already explained, the capacity cannot be neutralised in a practicable manner without introducing the effect of additional conductance; and, secondly, because the capacity

can only be neutralised at one particular frequency with a given combination of inductances.

If we consider a triple frequency term to exist in the E.M.F. generated in each phase winding of a Y-connected generator, we may consider all the phase windings in parallel as far as this term is concerned.

Let us consider such a triple frequency term by itself.

If the neutral-point be perfectly insulated and any leakage path whatsoever occurs at the poles, these will be at earth potential, and the potential of the neutral-point will differ from that of earth by the full amount of this triple frequency term. If, therefore, a triple frequency term exist, although the system be perfectly balanced, the potential of each pole in relation to earth will be very much modified by connecting the neutral-point to earth through a resistance, not only as regards the maximum potential difference, but also as regards the shape of the potential-difference wave. Fig. 10 represents an E.M.F. wave with a pronounced triple frequency term. If the neutral be perfectly insulated the sine curve represents the potential difference between each terminal and earth. If the neutral-point be earthed the peaked curve represents the potential difference. Thus, earthing the neutral-point may result in increasing the maximum potential difference of the terminals to earth.

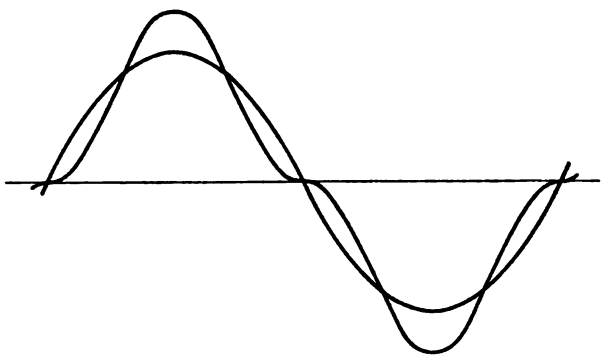


FIG. 10.

When the neutral-point is earthed through a resistance, the resistance must be low enough to cause the protective device to open the circuit should any pole become grounded, but at the same time it should be sufficiently amply proportioned to avoid the possibility of it burning out should the protective device fail. This implies that the resistance shall be capable of a very great rate of dissipation of energy without overheating. To overcome this difficulty, choking coils have been suggested in place of resistances.

The effect of a choking coil between neutral and earth will, however, be to still further increase the maximum potential difference of each pole to earth. This case is represented in Fig. 5. If a is the neutral-point and b represents the three terminals of the system, zero potential will lie somewhere below a. Since, however, $\frac{1}{l\theta}$ would be very great in comparison with $k\theta$ the increase of the maximum potential difference would not be important. Should, on the other hand, the choking coil be wrongly proportioned, or should high frequency terms exist in the E.M.F. wave, as sometimes occurs due to the number of slots per pole in the armature core, an undesirable increase of potential difference may be produced. Resistance introduced into the choking-coil circuit will serve more or less as a safeguard.

In the event of triple frequency terms being present in the E.M.F. generated in each phase winding, they will not appear, as is well known, in the voltages between poles.

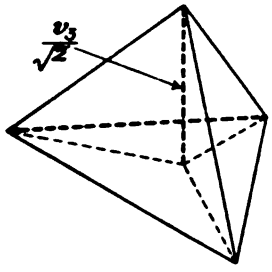


FIG. 11.

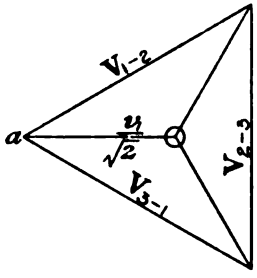


FIG. 11A.

If V_{1-2}, V_{2-3}, V_{3-1} be determined by direct measurement and the triangle constructed, the neutral-point must be considered as raised above the centre of the diagram (at right angles to the paper) by the amount of the triple frequency term (R.M.S. value), see Fig. 11, representing a triangular pyramid in perspective.

If the E.M.F. in a given phase is $v_1 \sin pt + v_3 \sin 3pt$, then the value of V_{1-n} etc., as measured, is $\sqrt{\frac{3}{2}}\, v_1$.

The potential difference between neutral and pole as measured will be $\sqrt{\frac{1}{2}(v_1^2 + v_3^2)}$.

In Fig. 11A, which may be taken as representing the base of the pyramid, $O\,a$ is $\frac{1}{\sqrt{2}}\, v_1$, hence, if the height of the triangular pyramid be $\left(\frac{1}{\sqrt{2}}\right) v_3$, the three inclined sides will have a length $\sqrt{\frac{1}{2}(v_1^2 + v_3^2)}$; they will therefore represent the magnitude of the

E.M.F. of each phase winding, but we cannot assign any phase relations to them from their positions in the diagram.

If the neutral-point be insulated and balanced leakage effects occur at the poles, the zero potential-point will lie in the base of the pyramid immediately under the apex; the effect of earthing the neutral-point will be to cause the zero potential-point to ascend to the apex.

The principles already explained may be further applied to the case of a primary and secondary system which are inductively interconnected.

In Fig. 12A a, b, c represents the primary E.M.F.'s of three transformers in 3-phase triangle grouping, and we will suppose that the conditions (elsewhere) are such that zero potential is at P_1.

The figure a', b', c' represents the secondary E.M.F.'s whose phase relations and magnitudes are determined by the magnetic relations

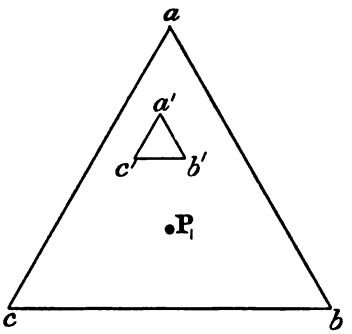


FIG. 12A.

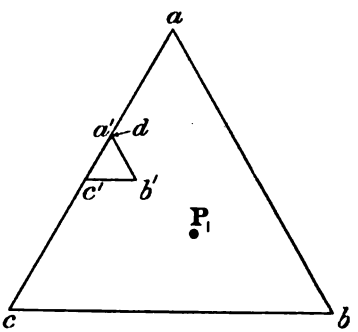


FIG. 12B.

connecting the primary and secondary systems. Obviously, the Z-point of the secondary system may or may not be at P_1, depending on the leakage conditions.

Suppose, for example, there were a fault in the primary to secondary insulation so that the point a' became connected to the point d, the position of the secondary system would be that shown in Fig. 12B. In fact, we may imagine the secondary system movable within the primary—but always with a motion of translation—its position depending upon the leakage effects between primary and secondary and between secondary and earth.

The question is what decides the position of the secondary in relation to that of the primary. Imagine the secondary moved about with a motion of translation until a position is reached where the total current leaking from primary to secondary at every instant is zero. Let this position of the secondary be defined by means of its Z-point, *i.e.*, call the position of the Z-point P_3 when this occurs.

Concentrate the whole of the primary-to-secondary leakage paths at P_3 and the whole secondary-to-earth leakage at P_1, the resultant Z-point

will be the actual Z-point of the secondary system, and this determines the position of the secondary in relation to the primary and earth.

Proof of this will be found in the Appendix. As an example, consider the 3-phase transformer combination in Fig. 13, and let the primary-to-secondary and secondary-to-earth leakage be symmetrical so that P_3 is at o.

We then concentrate the total primary to secondary leakage paths denoted by $\left[\frac{1}{R_p}, K_p\right]$ at o.

(R_p is the total insulation resistance, and K_p the capacity between primary and secondary.)

Next, suppose that owing to some fault in the external circuit earth

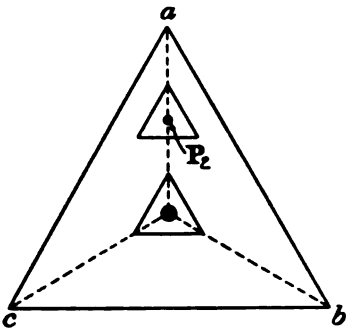


FIG 13.

potential is at *a*. We concentrate at *a* the total secondary leakage paths, or $\left[\frac{1}{R_s}, K_s\right]$, and find the resultant Z-point at P_2. This is the Z-point of the secondary system (see Fig. 13).

We thus see that if the leakage between primary and secondary be unbalanced, or the zero potential-point be not symmetrically located, the potential to earth of the secondary system as a whole may be considerably raised.

It is moreover obvious that the conditions might be such that the secondary system lay entirely external to the primary system.

If the generator be Y-connected and a triple frequency term exist in the E.M.F., although no such term can appear in the internal secondary E.M.F.'s, yet, if the neutral-point of the generator be earthed, a triple frequency term will be transmitted by electrostatic inductive action to the secondary system as a whole, that is to say, the potential difference between this system and earth will involve a triple frequency term.

APPENDIX.

So long as we consider that the internally generated E.M.F.'s follow sine laws we can represent them as vectors on the diagram ; but if the E.M.F.'s vary according to more complex laws, the diagram no longer conveys any meaning, and the centre of gravity analogy breaks down.

In this case, we can still speak of the potential of any imaginary external point, and to make the conception definite we assume it bound to the system by an E.M.F. equal to the difference of potential of the point in question and of that to which it is bound. We shall now see that the various theorems previously employed are true generally.

Consider a system with any number of leakage paths.

Let the nth leakage path be denoted by $\left[\frac{1}{r_n}, k_n\right]$.

Let v_0 be the value of the potential of some point of the system and let the potential of the nth leakage point be $v_n + v_0$. The internal E.M.F.'s being known we know the value of all terms such as v_n, and we wish to determine the value of v_0.

We have, then—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right)(v_n + v_0) = 0,$$

and if—

$$\frac{1}{R} = \Sigma\frac{1}{r_n} \text{ and } K = \Sigma k_n,$$

we have—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right) v_n + \left(\frac{1}{R} + K\theta\right) v_0 = 0,$$

or—

$$v_0 = -\frac{\Sigma\left(\frac{1}{r_n} + k_n\theta\right) v_n}{\frac{1}{R} + K\theta} \qquad \ldots\ldots\ (4)$$

Now, if $v_0 = f(t)$ be a solution of this equation, and $\phi(t)$ be such that $\left(\frac{1}{R} + K\theta\right)\phi(t) = 0$, then $f(t) + \phi(t)$ is also a solution of (4).

$\phi(t)$ represents the variation of potential of the whole system during the abnormal condition already referred to. It is obviously a non-periodic function.

It is quite evident that if the constants of all the leakage paths had been increased m times, the value of v_0 in (4) would remain unaltered.

II. Consider a combination of leakage paths, and let that at the nth leakage point be denoted by $\left[\frac{1}{r_n}, k_n\right]$. Let the Z-point be at P, and

let the potential of the nth leakage point in relation to that of the Z-point be v_n, we have then—

$$\Sigma\left(\frac{1}{r_n}+k_n\theta\right)v_n=0.$$

Now, introduce additional leakage paths so that the zero potential-point deviates from P. Let, now, the potential of P be v_0 and the total current to earth due to the additional leakage paths be c.

We then have—

$$\Sigma\left(\frac{1}{r_n}+k_n\theta\right)(v_n+v_0)+c=0.$$

or if—

$$\Sigma\frac{1}{r_n}=\frac{1}{R}\text{ and }\Sigma k_n=K,$$

$$v_0=-\frac{c}{\frac{1}{R}+K\theta},$$

but this is the result we should have obtained had we assumed the whole of the *original* leakage paths concentrated at P.

III. Consider a combination, so that the nth leakage path is denoted by $\left[\frac{1}{r_n},k_n\right]$ involving a Z-point at P_1, and let v_n be the potential of the nth leakage point in relation to that of P_1.

Then—

$$\Sigma\left(\frac{1}{r_n}+k_n\theta\right)v_n=0.$$

Next, consider a new combination of leakage paths which by themselves produce a Z-point at P_2. Let the individual leakage paths be represented by the general from $\left[\frac{1}{r_i'},k_i'\right]$ and let v_i' be the potential of the ith leakage point in relation to that of P_2; we have then—

$$\Sigma\left(\frac{1}{r_i}+k_i'\theta\right)v_i'=0.$$

Let—

$$\Sigma\frac{1}{r_n}=\frac{1}{R}\;;\;\Sigma k_n=K,$$

$$\Sigma\frac{1}{r_i}=\frac{1}{R'}\;;\;\Sigma k_i'=K'.$$

Now, suppose that the two combinations be introduced simultaneously, let the potential of P_1 be v' and of P_2 v''.

We have—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right)(v_n + v') + \Sigma\left(\frac{1}{r_i'} + k_i'\theta\right)(v_i' + v'') = 0,$$

hence also—

$$\left(\frac{1}{R} + K\theta\right)v' + \left(\frac{1}{R'} + K'\theta\right)v'' = 0.$$

But this is the equation we should have obtained had we considered

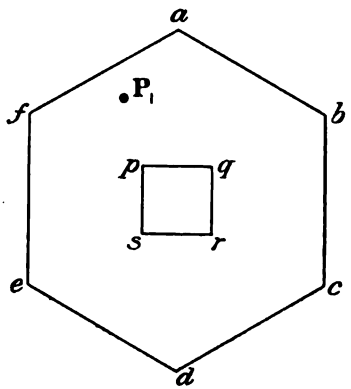


FIG. 14.

the whole of the first combination concentrated at P_1 and the whole of the second combination concentrated at P_2.

If—

$$\frac{1}{R} = 0, \text{ and } K' = 0,$$

we have—

$$K\theta v' + \frac{1}{R'}v'' = 0,$$

which indicates that in a system of distributed capacity and conductance leakage paths, we can consider each class separately, obtaining the Z-point as if this class alone existed.

We may therefore concentrate all capacity at one Z-point, and all conductance at another Z-point, and thus reduce the problem to a system of two leakage points.

IV. Let a, b, c, d, e, f be a primary system, and p, q, r, s a secondary system electromagnetically interconnected so that the phase relations and magnitudes of the internal E.M.F.'s are determined, see Fig. 14.

Assume the position of earth potential is at P_1, this being fixed by

considerations outside the system under discussion. So long as the secondary leakage paths remain constant, the Z-point of the secondary system will have a definite position in relation to the boundary p, q, r, s. If the leakage paths between primary and secondary vary, the secondary system will move with a motion of translation within the primary, but the Z-point will move with it, maintaining its relation thereto.

There are three points to be considered : the zero potential-point P_1, the actual position of the Z-point of the secondary system P_2, and the position this would have to occupy in order that the total leakage current from primary to secondary might be zero at every instant, P_3.

If v_0 be the potential of the secondary Z-point, the total current flowing is obviously—

$$\left(\frac{1}{R_s} + K_s\theta\right)v_0,$$

where R_s is the total insulation resistance and K_s the total capacity of the secondary system.

Now, the primary and secondary systems are connected by leakage which paths we may express by the general form—

$$\left[\frac{1}{r_n}, k_n\right].$$

If v_n is the potential difference acting between the primary and secondary along the nth leakage path, the total current flowing from primary to secondary may be expressed as—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right)_p v_n \quad \ldots\ldots\ldots \quad (5)$$

Hence we have—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right)_p v_n - \left(\frac{1}{R_s} + K_s\theta\right)v_0 = 0 \quad \ldots\ldots \quad (6)$$

Now, imagine that the whole of the secondary system with its Z-point could be moved so that the potential of the Z-point is $v_0 + v'$ instead of v_0 as previously.

Then the current flowing from primary to secondary would be—

$$\Sigma\left(\frac{1}{r_n} + k_n\theta\right)_p v_n - \left(\frac{1}{R_p} + K_p\theta\right)v',$$

where $\frac{1}{R_p}$ and K_p are the total conductance and capacity respectively of the leakage paths between primary and secondary.

Let v' be so chosen that this expression is zero (obviously this is possible), then (6) becomes :—

$$\left(\frac{1}{R_p} + K_p\theta\right)v' - \left(\frac{1}{R_s} + K_s\theta\right)v_0 = 0.$$

Let us now consider the three points: zero potential P_1, the Z-point P_2, and position of Z-point P_3, in order that the total primary-to-secondary leakage may be zero.

The potential difference $P_3 - P_2$ is v', and the potential difference $P_1 - P_2$ is $-v_0$, hence if we consider a 2-leakage point system with poles at P_3 and P_1 and concentrated leakage paths at these poles of $\left[\frac{1}{R_3}, K_3\right]$ and $\left[\frac{1}{R_1}, K_1\right]$ respectively, the above equation would define the position of the Z-point, v' being the potential of P_3 to Z-point, and $-v_0$ that of P_1 to Z-point.

If, then, from symmetry or otherwise we can determine the position of P_3 and we know the position of the zero potential-point, we consider the total primary-to-secondary leakage, and the secondary-to-earth leakage concentrated at these poles, and the resultant Z-point is the actual Z-point of the secondary system.

The application of this principle has already been indicated.

JOURNAL

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Proceedings of the Four Hundred and Seventy-third Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 19, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 12, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

J. C. Macfarlane. | F. L. Monkhouse.

From the class of Associates to that of Associate Members :—

Oliver H. Bishop. | H. Stansfield.

Messrs. F. Bourne and E. H. Rayner were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Robert Blackmore.	John Hey.
Arthur Leonard Boyle.	David James.
Karl Martin Faye-Hansen.	Hugh Cecil Ogilvie.

Benjamin Smith.

The following paper was read and discussed :—

NEW ALTERNATE-CURRENT INSTRUMENTS.

By W. E. SUMPNER, D.Sc., Member, and J. W. RECORD, Associate Member.

(*Received from the* BIRMINGHAM LOCAL SECTION, *November* 7, 1907, *read in London on March* 19, *and at Birmingham on April* 8, 1908.)

SUMMARY.

INTRODUCTION.

SHUNT-MAGNET INSTRUMENTS.—The Structure of the Magnet and the Moving System—The Quadrature Transformer—Wattmeter Circuit Connections—Magneto static Voltmeter—Portable Standard Instruments—Capacity Measurements.

INSTRUMENTS FOR PHASE MEASUREMENT.—Idle-current Ammeters—Iron-cored Phasemeters—Voltage-wound Phasemeters.

CALIBRATION AND ACCURACY.—Wattmeters and Voltmeters—Phasemeters.

APPENDIX.—Note 1. Summation Wattmeter—Note 2. Neutral Point Reactance Coil for Shunt-magnet Wattmeters.

INTRODUCTION.

The instruments referred to in this paper are the outcome of an investigation on the properties of iron-cored electromagnets for use in alternate-current instruments. Two papers dealing fully with the theory and testing of these instruments have already been published.* We do not propose to reproduce any matter contained in those communications, but to describe the instruments as actually constructed, and to state their uses and properties. We shall rely on the papers referred to as theoretical evidence for the truth of the assertions made.

It is nevertheless desirable again to point out the idea which forms the basis of the whole matter. Iron-cored instruments are not new, and their advantages as regards sensitiveness are well known. But to make such instruments accurate it is necessary to have a magnet the strength of which depends upon the excitation in a manner independent of the variable physical properties of the core, such as permeability, hysteresis, etc. Such electromagnets are not to be found in commercial instruments as hitherto made. It is in this connection that the fundamental difference between the series magnet and the shunt magnet is so important. When a magnet is series excited, by a current through the field winding, the flux which is produced depends upon the current and on the physical properties of the core, but is

* "The Use of Iron in Alternate-current Instruments," *Journal, Institution of Electrical Engineers*, vol. 34. "New Iron-cored Instruments for Alternate-current Working," *ibid*, vol. 36

quite independent of the resistance of the winding. The strength of the magnet caused by a given current is the same for a winding of manganin wire as for one of copper wire. But if the magnet be excited by the voltage, the flux is controlled by this voltage, and does not depend upon the properties of the core. This would be true with mathematical accuracy were it not for the resistance of the winding. Provided this resistance can be made small compared with the impedance it does not matter whether the core of the magnet be of iron, or of brass, or of wood. In all cases the flux in the magnet will be determined by the exciting voltage and by the winding, not by the core. Variations in permeability or eddy currents affect the magnetising current, not the magnetism produced. If the voltage is doubled the magnetism must also be doubled, whether the permeability does or does not remain the same in the two cases.

With the shunt magnet the eddy currents caused in a small piece of brass do not affect the magnetism caused by the exciting voltage. In the construction of the wattmeters now to be described it is thus permissible, within reason, to use brass clamping-pieces in the neighbourhood of the moving system. This is an important advantage from a maker's point of view. With a series magnet, on the other hand, the eddies induced in a piece of solid metal do affect the magnetism caused by the exciting current, and hence in the ordinary dynamometer wattmeter, or in the special quadrature current transformers referred to in this paper, it is vitally important to prevent such eddy currents from arising.* The strength of the *series* magnet for a given current is dependent on the properties and the past history of its core. The field of the *shunt* magnet, on the other hand, is independent of the core, and is perfectly controlled by the voltage applied at the moment. It is not affected by any ageing effect in the core, and the field is thus even more reliable than that of a permanent magnet as used in direct-current instruments.

The field of the shunt magnet, though caused by the voltage, is not in phase with it. Special means must be devised for supplying the movable coil with such a current as to make the deflection of the instrument a correct measure of the quantity to be tested. This may at first seem difficult, but, as a matter of fact, is quite easy to do. For the wattmeter a special form of current transformer is needed. For the voltmeter any ordinary condenser may be used. These accessories we call quadrature transformers, since their function is to produce a moving-coil current which is in quadrature with the circuit current or voltage. They correspond in many ways with the shunt or series resistances used with permanent magnet ammeters and voltmeters. The indicating instrument itself has the characteristics and advantages of permanent magnet instruments. Strong controlling springs can be used. Stray magnetic fields have no influence on the readings, while the currents

* The theory of the disturbing effect of eddy currents on the action of dynamometer wattmeters was first given by one of the present authors in 1892. See *Journal, Institution of Electrical Engineers*, vol. 21, pp. 743–745.

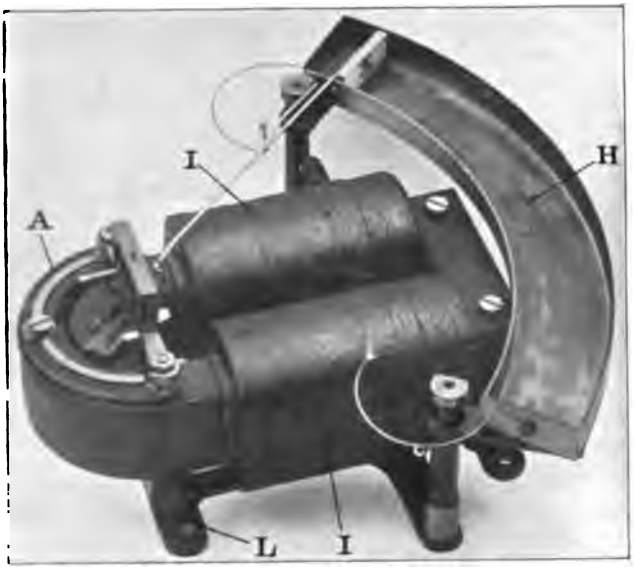


FIG. 1.

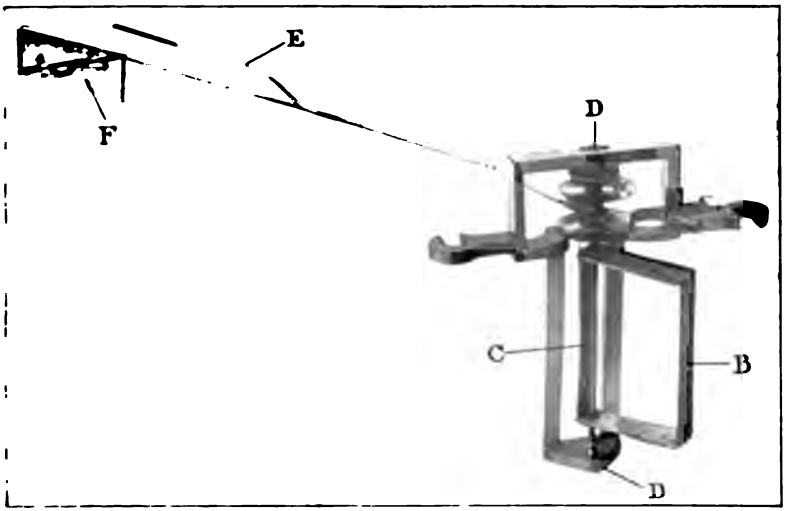


FIG. 2.

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actually used in the coils are very small, so that the instrument, like a voltmeter, can readily be switched from one circuit to another.

It will not at once be seen that the readings of the instrument are independent of frequency, and also of the wave-forms of the current and voltage. A complete mathematical proof of this has been given in the papers already referred to.

As regards change of frequency, it may be pointed out that the field of the magnet when excited by a given voltage will be doubled if the frequency is halved, but the moving-coil current will at the same time be halved, so that the product of field and moving-coil currents will be independent of frequency, and it is this product that determines the deflection.

Shunt-magnet Instruments.

The Structure of the Magnet and of the Moving System.—The design of instruments with laminated field magnets suitable for alternating current presents many difficulties, especially when a short air-gap is essential in which to swing a moving coil. The laminations themselves cannot be satisfactorily used for a base or foundation to carry other portions of the mechanism, but, on the contrary, they must themselves be most securely fastened to a framework that has been prepared to hold them together with the other parts in fixed relative positions to each other.

Laminated magnets for alternating-current work likewise cannot be ground or filed, and when the laminæ are assembled to form a block, if their edges are not even, the necessary truing can only be done at the risk of separating the laminæ to clear off the burrs caused by the filing, and reassembling once more. Almost any known form of electromagnet which would permit a coil of wire to swing between two pole-faces could have been selected for these instruments, but partly on account of the above difficulties it was decided to design a magnet with a single air-gap, which at once lessens the difficulty of obtaining smooth, regular pole-faces. The total length of air-gap, or the distance of one pole from the other, is only 0·08 of an inch, giving a clearance of 0·02 of an inch each side of the moving coil. It will be seen that a very slight projection of a stamping will foul the moving coil.

The particular form of magnet shown in Fig. 1 has also been selected in order to reduce the magnetic reluctance of the circuit to a minimum, on account of its easy mechanical construction, and to allow a large angular deflection of the pointer when necessary. The block of iron stampings A is securely clamped on a brass framework L. The cross-section of the iron is about 1 sq. in., the total magnetic flux is approximately 32,000 C.G.S., and the flux density about 5,000 C.G.S. (R.M.S. values), at the normal applied voltage on 50-$\sim$ circuits. As the section of the gap is five or six times that of the iron core the flux density in it is correspondingly reduced. It is generally about 1,000 C.G.S. lines per square centimetre, and is comparable with that used in the air-gaps of good permanent magnet instruments.

To reduce the copper drop to the least possible amount the largest size copper wire that can be wound in the available space is used. About 200 ampere-turns are needed to produce the flux under normal conditions.

The moving coil B consists of about 40 turns of fine copper wire former wound, and fixed to an axle fitted with hardened steel pivots and supported between jewelled screws D D (see Fig. 2).

The effect of temperature variations on the copper windings is completely swamped by the use of about 80 ohms of manganin wire wound non-inductively and joined up in series. This extra resistance also serves the purpose of nullifying the slight deflection which would otherwise be produced by induction if the terminals of the moving coil were short-circuited. It will be noticed that the pointer E and damping vane F are placed so that their weight as nearly as possible

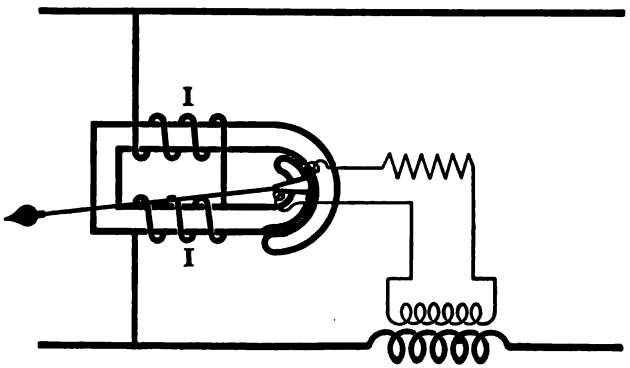


FIG. 4.

balances the weight of the moving coil, thus the inertia of the moving system is not increased by the use of extra masses for balancing purposes. Owing to very careful balancing all gravity control is eliminated, and accurate readings of the instrument can be taken without previous levelling.

In order to cheapen construction and for ease in assembling the parts the frame for holding the moving coil, controlling springs, etc., is so constructed that it can be removed completely from the iron core without disturbing the latter, and without disconnecting the connections or removing the instrument from its case. It is shown separately in Fig. 2.

An air chamber H for damping down the oscillations of the pointer is provided, and the dial of the instrument forms the top of this dash-pot. I, I are the exciting, or field coils, of the electromagnet placed in shunt across the mains (see Figs. 1, 3, and 4).

The torque on the moving-coil system is about 1·2 gramme-centi-



FIG. 3.



FIG. 13.—Double Scale for Portable Instrument (p. 10).

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metres for 90° deflection, which is greater than that usually employed with instruments of the dynamometer or induction type.

The photograph (Fig. 3) shows the appearance of a switchboard-type instrument with case cover removed. It will be noticed that the scale markings are very evenly spaced.

The Quadrature Transformer.—In order that the instrument may read watts it is necessary to connect the electromagnet in shunt across the mains, and to join the terminals of the moving coil to the secondary of a specially designed current transformer. To distinguish this transformer from one of the ordinary series type we call it a "quadrature" transformer.

This transformer renders the current in the moving coil proportional to the current in the mains, and the product of the moving-coil current into the air-gap flux becomes a measure of the load whatever the voltage, current, frequency, or wave-form. (The small error due to

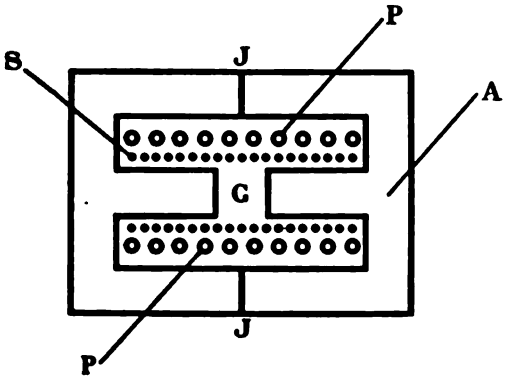


FIG 5.

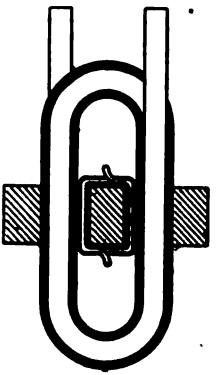


FIG. 6.

power factor is discussed later.) It is the introduction of the quadrature transformer that has made the iron-cored wattmeter possible, as it combines not only the function of producing a secondary current which is directly proportional to the primary current for all values of the latter, but also a current which is 90° out of phase with the primary current, and therefore in correct phase relation to the magnetic flux in the air-gap of the electromagnet. The core A in Fig. 5 is formed of two blocks of iron stampings with butt joints at J, J and an air-gap G, generally about one-tenth of the length of the iron circuit. P is the primary winding and S the secondary. The latter consists of a few turns of fine wire, the ends of which are joined through a high non-inductive resistance to the terminals of the wattmeter moving coil. It is this long air-gap in the quadrature transformer that renders the flux proportional to the primary current for all changes in its value, and reduces the error due to hysteresis in the iron to a negligible quantity. If we take 1,000 as an average value for the permeability of the iron, it

will be apparent that the reluctance of the gap is about 100 times that of the core, so that the reluctance of the magnetic circuit is essentially independent of the effects of the variable magnetic properties of the core. (For full theory see *Journal*, vol. 36, pp. 462–467.)

Fig. 6 illustrates a quadrature transformer insulated for high-tension circuits.

For large currents two further types of quadrature transformer are made, one in the shape of a ring, to slip over cables, the other rectangular to slip over busbars.

It must be remembered that ordinary series or current transformers are quite unsuitable for use with these wattmeters, as their secondary currents are in phase (or 180° out of phase) with their primaries, but it

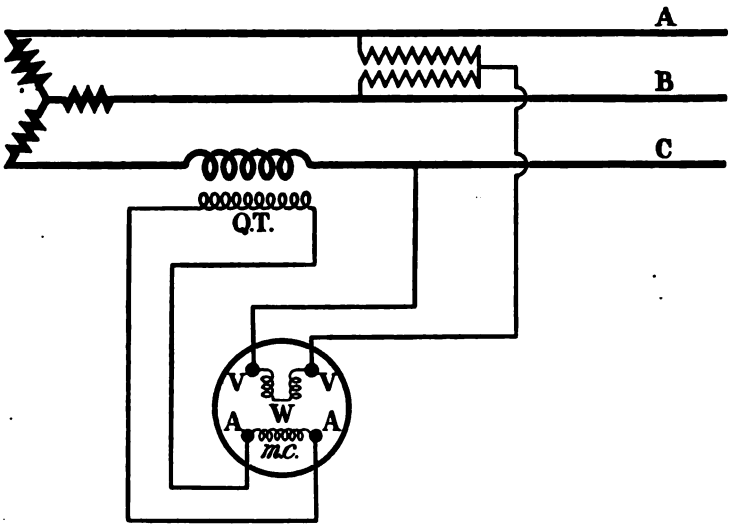


FIG. 7.

is permissible, although not advisable, where series transformers are already installed, to connect the primary of the quadrature transformer in series with the ordinary current transformer secondary. The accuracy of the wattmeter will, however, be limited by the magnitude of the phase error of such series transformers.

Switchboard designers are prone to actuate induction ammeters, relays, trip coils, wattmeter series coils, etc., from small instrument current transformers, losing sight of the fact that the accuracy of the wattmeters is thereby often destroyed. This practice should, as far as possible, be avoided.

Wattmeter Circuit Connections.—Fig. 7 shows how the instrument should be connected to the circuit for measuring the power of a 3-phase circuit, balanced load, when the neutral point is not available.

A specially designed choking coil is used, with its ends connected to two of the mains, the wattmeter itself being joined to the third main and to the junction point of the choking coil. The total power of the circuit so connected is equal to twice the wattmeter reading, or the instrument may be graduated to indicate total power direct. (For theory see Note 2, Appendix.)

For high-tension circuits potential transformers are necessary to reduce the potential to a safe value for the instrument. Such transformers are connected with their secondaries in opposition in order to bring the voltage into proper phase relation with the current. The connections of this are shown in Fig. 8. One quadrature transformer only is used, and two potential transformers with opposed secondaries. In Fig. 9 an equivalent arrangement is shown in which one potential

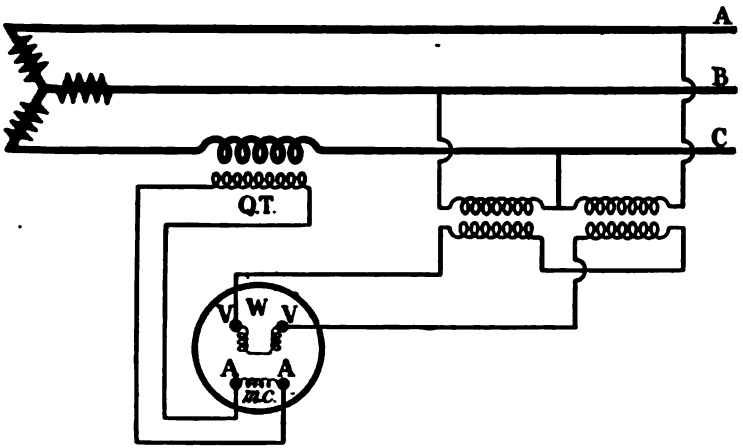


FIG. 8.

transformer and two quadrature transformers are employed, the secondaries of the latter being parallel connected in opposition as regards the moving coil.

The ease with which the wattmeter can be connected with, or disconnected from, the main circuit, without disturbing the latter, renders it suitable for a number of special purposes. For instance, the output of each of a number of alternators in parallel may be measured in succession by using *one* indicator and as many current transformers as there are alternators in parallel; by the addition of another transformer the total output can also be measured. Such a method is indicated in Fig. 10. A multiple switch is used to connect in turn the various quadrature transformers, $Q T_1$, $Q T_2$, $Q T_3$, and $Q T_4$, to the indicator. As an example, suppose there are three alternators, having outputs of 200, 500, and 1,000 k.w. respectively, with line voltage 2,000, on a 3-phase balanced load. The line currents will

be 58, 145, and 290 amperes, and total current about 500 amperes. If the quadrature transformers $Q T_1$, $Q T_2$, $Q T_3$, and $Q T_4$ are respec-

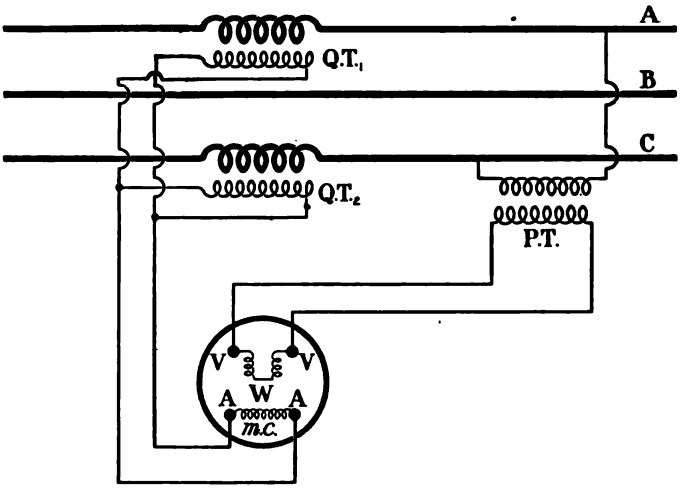


FIG. 9.

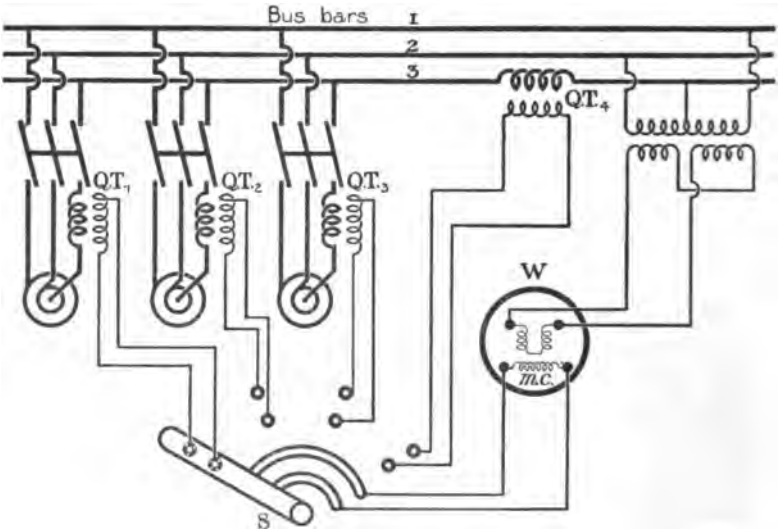


FIG. 10.

tively of these capacities, and the corresponding secondary resistances are properly adjusted, the wattmeter pointer will correctly indicate the corresponding power whichever one is connected by the switch S.

If the scale is divided into 100 divisions the constants will be as follows :—

Q T_1	for 200-k.w. machine ; output	=	instrument reading	×	2.
Q T_2	„ 500-k.w. „ „	=	„ „	×	5.
Q T_3	„ 1,000-k.w. „ „	=	„ „	×	10.
Q T_4	„ total output	=	„ „	×	20.

It is quite safe to put the secondaries of quadrature transformers on open circuit, because, unlike series transformers, the demagnetising effect of the secondary current is nil. The value of this current is less than $\frac{1}{10}$th ampere, so that an ordinary voltmeter switch may be used.

Another arrangement for measuring the total output of a number of generators when it is not possible to use a transformer like Q T_4 in Fig. 10 is explained in Note 1 of the Appendix.

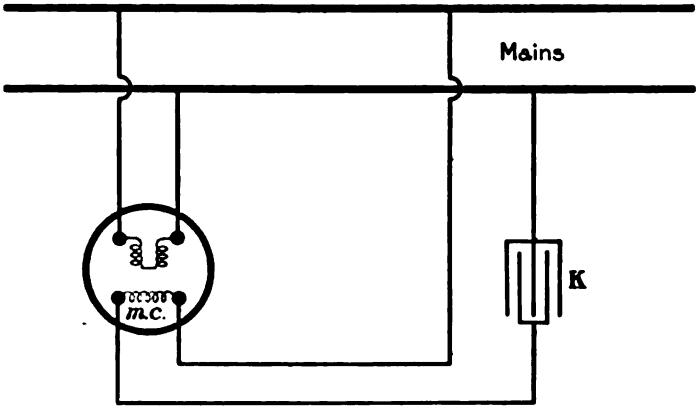


FIG. 11.

Magnetostatic Voltmeters.—The wattmeter may be used to measure volts by changing the connections of the moving coil from the secondary of the quadrature transformer, and placing them in series with a condenser of suitable capacity across the mains (see Fig. 11). The readings will be correct on circuits of any frequency or wave-form, provided the ratio of voltage to frequency is not made too great so that the resultant induction density in the iron is made excessive.

The magnetic flux, which is proportional to this ratio, should not be allowed to exceed the normal value by more than 50 per cent. for a sustained load. An instrument designed normally for use on a circuit of 100 volts, at a frequency of 50 ∿, will accurately respond to an increase of 50 per cent. in the voltage if the frequency remains at 50 ∿, but on circuits of 25 ∿ it is not allowable to increase the voltage above the normal. The limiting factor is the ratio of voltage to frequency.

This ratio for the above instrument is normally 100/50, or 2, and when increased by 50 per cent. it becomes 3. On circuits of 50 ∿ the maximum voltage advisable is therefore 150, while the lowest frequency at which it should be left subjected to 100 volts is 100/3 or 33⅓ ∿.

Portable Standard Voltmeter and Wattmeter.—The laboratory portable standard instrument is most useful, and the measurements to which it is adapted are so many and varied that it can be considered an alternating-current testing set. It consists of a mahogany case containing the movement already described, and is provided with four terminals and two switches. The internal connections can be traced from Fig. 12. It will be seen that with switch A in one position the coils of the electromagnet are connected in parallel, and the pointer

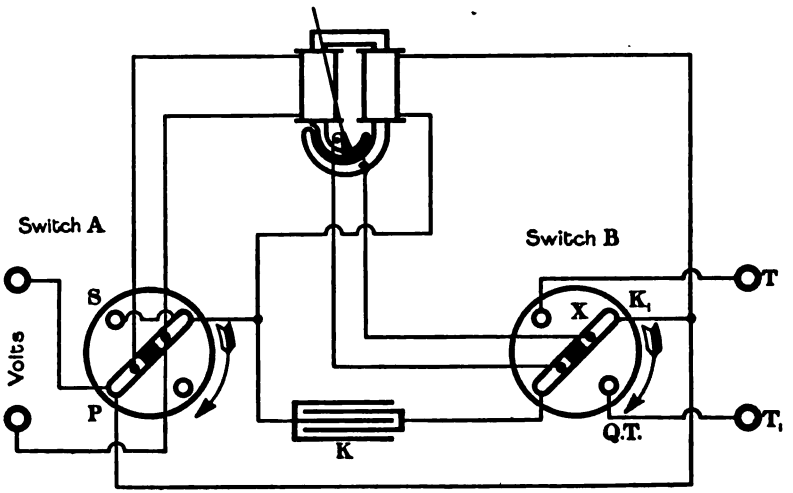


FIG. 12.

will deflect to its maximum position for the rated voltage; and that with switch A in the second position the coils are connected in series, and twice that voltage will be needed to produce the same deflection.

Switch B is for connecting the moving coil either in series with a condenser K across one of the field coils, or directly across terminals T and T_1. It will be noticed that the voltage applied to the condenser is the same for the same voltage per turn applied to the field coils, whether these latter are series- or parallel-connected.

With switch B in the position shown in Fig. 12, the instrument is a direct-reading voltmeter having two ranges; the readings are quite independent of frequency, wave-form, hysteresis, stray magnetic fields, or electrostatic influences. As the flux in the air-gap is proportional to the applied voltage, and the condenser current is also proportional

to the applied voltage, it follows that the torque acting on the moving coil must be proportional to the square of the voltage. A double scale typical of the portable instrument is shown by Fig. 13 (see page 229). A square law scale may at first sight seem undesirable, but will be found usually an advantage in practice, because readings are seldom required much above or below the normal circuit voltage. Readings near the lower portions of the scale are very little used, whilst those near the working voltage are required to be clear and open. To a laboratory instrument this does not so much apply, but it must be remembered that the portable type is fitted with a change-over switch for altering the range of the voltmeter.

A useful form of quadrature transformer for portable use consists of an ordinary quadrature transformer with a subdivided primary, the ends of which are taken to separate pairs of terminals. These terminals can be connected in series, series parallel, or parallel. For instance, a transformer with four separate primary coils, each wound for 5 amperes, will be suitable (i.) for 5 amperes if connected all in series, (ii.) for 10 amperes if connected 2 in series and 2 in parallel, and (iii.) for 20 amperes if connected all in parallel.

The full scale deflection of the wattmeter will be obtained for either of these combinations, but the reading must be multiplied by the correct constant to convert to watts.

Capacity Measurements.—When the switch B of Fig. 12 is turned to join the moving coil across $T T_1$, the instrument can be used for a wattmeter or for a variety of special purposes, one of the most useful being the measurement of capacity of cables and condensers.

It is universally admitted that the present methods of testing capacity are both tedious and unreliable. A condenser that is leaky cannot easily be measured correctly with a ballistic galvanometer. The test is always very slow and troublesome; errors occur due to residual absorption, and others sometimes arise from electrolytic and similar effects.

Condensers are manufactured in hundreds of thousands for telephone use, and require to be quickly tested. Alternating-current ammeters are sometimes used for the purpose in preference to the slow ballistic galvanometer method, but the results are hopelessly influenced by complicated effects due to variation of wave-form and frequency.

The iron-cored voltmeter here described is essentially free from all these defects. Any leakage current in the condenser, being in phase with the volts, is in quadrature with the magnetic field, and hence has no influence on the deflection, while changes of frequency and wave-form likewise cause no errors.

The condenser fitted in the instrument for using this as a voltmeter can be also employed as a standard of capacity, and a special scale can be made for the instrument so that this is direct reading in microfarads for tests at any convenient fixed voltage. The readings on this capacity scale will be proportional to the readings on the watt scale, and

hence proportional to the square of the readings on the volt scale. If the voltage remains constant for consecutive readings, a direct comparison of capacities can be quickly made.

If—

K_1 = capacity of condenser in case,
K_2 = capacity to be tested,
W_1 = deflection for the capacity K_1,
W_2 = deflection for the condenser or cable tested,

then—

$$K_2 = K_1 \frac{W_2}{W_1}.$$

The readings W_2 and W_1 must be taken on the capacity, or watt, scale. Since for a given voltage W_1 is fixed, the scale can easily be

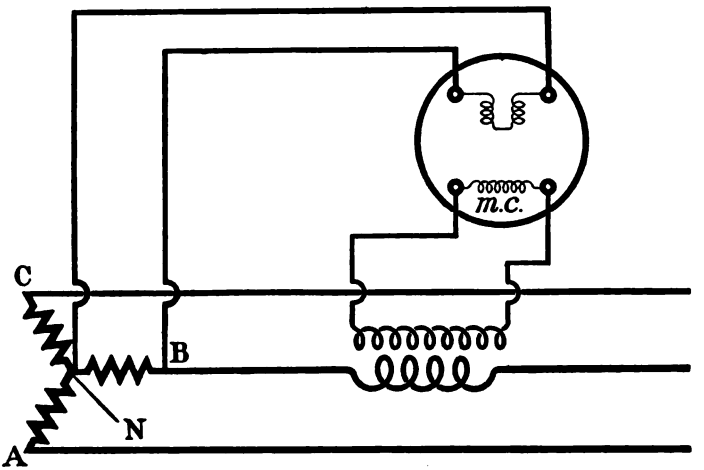


FIG. 14.

graduated to make K_1/W_1 a simple constant for the specified voltage. In some cases, if the voltage used were the same for W_1 as for W_2, the capacity to be measured would be large enough to cause the pointer to deflect off the scale. The deflection W_1 for the instrument condenser K_1 can then be taken at some voltage V_1 as read by the instrument, when connected up as a voltmeter, either on the volt scale as V_1, or on the watt scale as ω_1. The deflection W_2 for the unknown capacity K_2 may be noted at a reduced voltage V_2 (or ω_2 on the watt scale). We shall then have—

$$K_2 = K_1 \frac{W_2}{W_1} \frac{V_1^2}{V_2^2} = \frac{W_2}{W_1} \frac{\omega_1}{\omega_2} K_1,$$

$$= \frac{K_1}{W_1} \times \frac{\omega_1}{\omega_2} \times W_2,$$

in which the first factor is a constant of the instrument; the second

factor depends on the voltages used; and W_s depends on the condenser tested.

In comparing capacities, readings are best taken on the watt scale, which is equally divided, whilst the actual voltage, when needed, can be directly read off the volt scale.

Whilst speaking of capacity, it will be interesting to mention that the firm who manufacture these iron-cored instruments make the condensers used with the present voltmeters, and also thousands of others for telephone work. The above method is employed, with the most satisfactory results, for measuring the capacity of these condensers, which are made by a patented process, and have been found perfectly reliable for voltmeters of the present type.

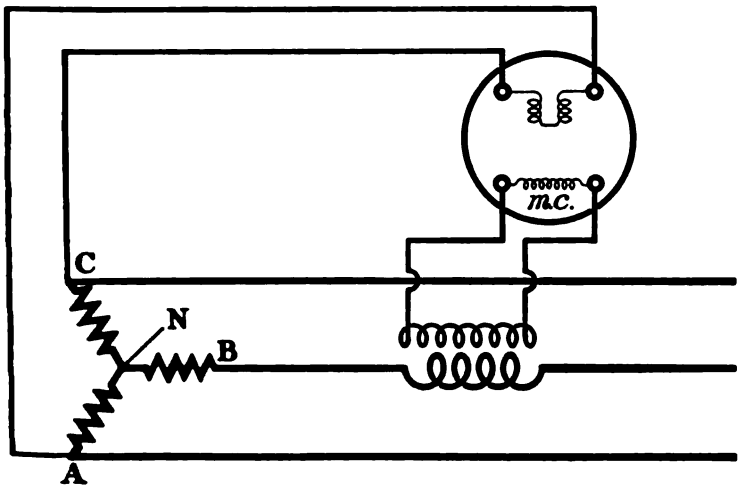


FIG. 15.

INSTRUMENTS FOR PHASE MEASUREMENT.

Idle-current Ammeter.—For constant voltage circuits the wattmeter can be used as an idle-current ammeter. For single-phase circuits all that is necessary is to substitute for the quadrature transformer a non-inductive strip resistance, to which the moving coil is suitably shunted; or, alternately, an *ordinary* current transformer with a secondary coil of many turns short-circuited by the moving coil. For 3-phase circuits it is only a matter of changing the connections of the potential leads; this is shown in Figs. 14 and 15.

Fig. 14 shows the instrument as normally joined up to the mains, through a quadrature transformer, so as to read the watts of the circuit. By disconnecting the volt coil from N B and joining the leads to the points C A, the applied voltage is turned through 90° relative to the current,

and for unity power factor loads the meter will read zero. For lower power factors the instrument will indicate V A sin ϕ, and may be calibrated to read the wattless current for the line voltage used.

Iron-cored Phasemeters. — Phasemeters are instruments analogous to ohmmeters, and the theory of their working is similar and almost as simple. An ohmmeter contains a moving system, consisting of a magnetic needle N, and a fixed system of two coils traversed by currents A_1 and A_2, whose ratio is represented by the position of the pointer; this deflection can thus be calibrated to indicate ohms or megohms.

The currents A_1 A_2 produce two magnetic fields O F_1 and O F_2, usually, but not necessarily, at right angles, and the needle takes up the position corresponding with the resultant field, indicated by the pointer O P (see Fig. 16). The calibration of the scale depends on the structure and winding of the coils, but, for any given instrument, is solely determined by the ratio of the currents A_1 and A_2. If the currents are alternating, and the strength of the needle N is also alternating, the position taken up will depend on the ratio of the two mean products A_1 N and A_2 N, and this ratio will merely depend on the phase differences between A_1, A_2, and N, if the ratio of the R.M.S. values of A_1 and A_2 is constant, as is necessarily the case in a balanced multi-phase system of currents. The phasemeter is merely an ohmmeter, having, in effect, an alternating magnetic needle N, due to the flux caused by an alternating current traversing a moving coil, and having two alternating magnetic fields O F_1 O F_2 in fixed directions (but not in the same phase) due to the cyclic currents through its fixed coils.

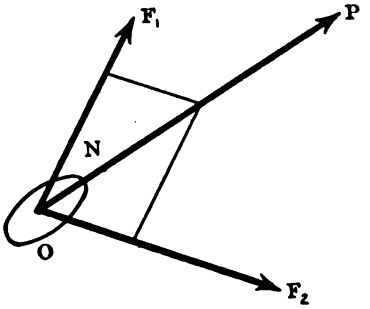


FIG. 16.

Usually a phasemeter consists of a fixed and moving system of coils, one system containing two coils and the other only one. As regards the theory, it is immaterial whether the fixed or moving system is actuated by the main currents, provided the other system is actuated by the voltages; and it does not matter, in the case of either coil system, whether this system consists of one, two, or three coils, provided three or more coils in all are used for the two systems. The instruments here described have only one coil in the moving system, but contain three coils, C_1, C_2, C_3, in the fixed system, the latter being traversed by currents representing A_1, A_2, and A_3, the three currents of the 3-phase mains. But these currents are necessarily such that one of them, say A_3, can always be regarded as the sum of the other two, so that the three coils, C_1, C_2, and C_3, just mentioned, can really be regarded as only two coils, having a portion C_3 in common, one of



FIG. 18.

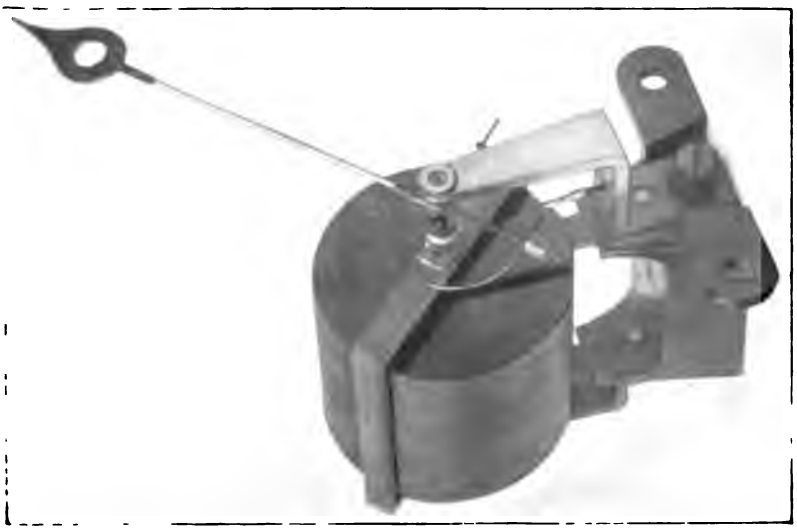


FIG. 19.

shunt across the mains. One mode of connection suitable for a 3-phase circuit is shown in Fig. 21.

Various arrangements of transformers, analogous to those stated in connection with the wattmeter, may be used with the phasemeter, but owing to the number of circuits in the instrument, and to the fact that resistances, transformers, or condensers may each be used with them, the number of possible combinations is so great that a mere summary of them would take too long.

Fig. 22 shows an arrangement for a power-factor meter suitable for connection to a constant frequency single-phase circuit. It will be noticed that the indicator itself is identical with that of the multi-phase instrument; the stator has the same distribution of coils, but in order

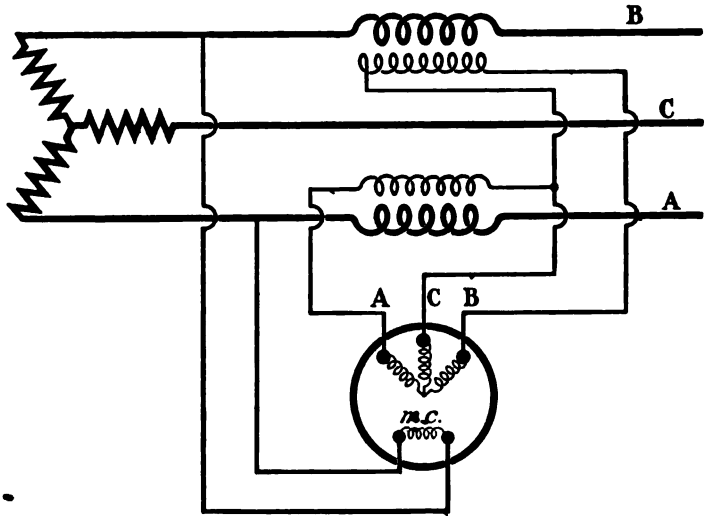


FIG. 21.

to supply these coils with currents in suitable phase relation, a special transformer is necessary. This transformer T (Fig. 22) is of the ordinary current type, with a connection C taken from the middle point of the secondary winding A, C, B. C is joined to C of the phase-meter, and A and B are each joined to the corresponding terminals of the instrument, A through a non-inductive resistance R, and B through an inductive resistance I. The moving coil is joined through a suitable resistance either direct to the mains or to the secondary of a potential transformer whose primary is in shunt to the mains.

Voltage-wound Phasemeters and Synchronisers.—A form of phase-meter is being developed, having its stator coils wound for voltage and its moving coils for current, the latter being supplied either from a shunt or from a current transformer. Experiments are also being carried

out on an instrument of the above type, which has been so constructed that the moving coil is free to revolve continuously in either direction. When these forms are fully developed it will be a simple matter, with the aid of a voltmeter switch, quickly to change the instrument from one alternator to another in a similar manner to that used for the wattmeter shown in Fig. 10; also by connecting the voltage windings to the busbars, and the moving coil to the terminals of an incoming machine, the phasemeter will be converted into a synchroniser. It will indicate if the incoming machine is "too fast" or "too slow" by revolving either clockwise or anti-clockwise. When the pointer comes to rest the speed will be right, and, by further regulation, the

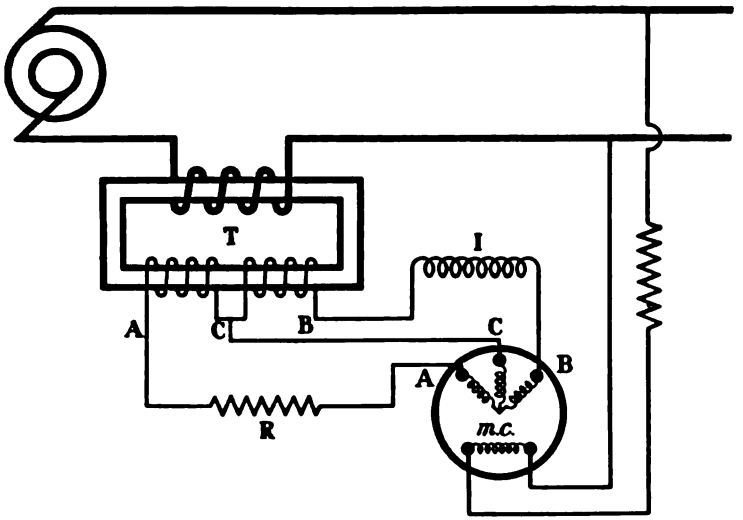


FIG. 22.

pointer will turn and become stationary in the normal position, and this will indicate the correct moment for switching in.

CALIBRATION AND ACCURACY.

Wattmeters and Voltmeters.—A simple direct-current test is used to determine the wattmeter scale. (See *Journal*, vol. 36, p. 429.) The same method may be used for the voltmeter, since the scale markings in the latter case are proportional to the square root of the corresponding scale markings in the case of the wattmeter (see Fig. 13, page 229). The instruments are afterwards adjusted on an alternate-current circuit against a standard instrument; for a wattmeter by an adjustment of the resistance of the moving-coil circuit, and for a voltmeter by the choice of a suitable condenser, followed by a final adjustment of the spring.

The scales prepared in this way have been found quite accurate for alternate-current circuits.

The error of an instrument in actual working is frequently more due to extraneous influences, such as friction or disturbing fields, than to incorrect electrical action on the moving system. From such disturbing influences the present instruments are well guarded, owing to the strong controlling springs used and to the natural shielding due to the iron employed in their construction. Moreover, the deflection cannot be influenced by eddy currents, which may be induced in the iron case or other metal parts near the moving coil.

Numerous experiments already published in the *Journal* (vol. 36, pp. 435–450) have shown that the present instruments act correctly for changes in voltage, current, or frequency, and that the error for variations of power factor obeys the law applicable to all wattmeters, the error as a fraction of the true reading being given by $\theta \tan \phi$, where θ is a quantity characteristic of the instrument, and which may be conveniently called its *phase error*.

In Table I. below the wattmeter error for a phase error of 1 per cent. of a radian ($\theta = 0{\cdot}01$) is expressed in three ways for loads of different power factors.

TABLE I.

Wattmeter Error for a Phase Error θ of 1 per Cent.

Power Factor, Cos ϕ.	Per Cent. of True Watts, 100 θ tan ϕ.	Per Cent. of Volt-amperes, 100 θ sin ϕ.	Millimetres on Scale.
1.0	0	0	0
0·9	0·48	0·43	0·55
0·7	1·02	0·71	0·90
0·5	1·73	0·87	1·10

In the second column the error is expressed as a percentage of the true watts. The third column shows the error as a percentage of the volt-amperes, or of the watts associated with the same current and voltage on a non-inductive load. The last column expresses the error as a shift of the pointer in millimetres on the scale, assuming that a deflection measuring 5 in., or 127 mm., denotes a power in watts numerically equal to the volt-amperes.

For commercial purposes, the error is sufficiently small if kept within a small fraction of the full deflection, and is always negligible if the corresponding shift of the pointer is within the error of reading under working conditions. In normal working full deflection is only attained for the circuit voltage at full-load current, when the

power factor is unity. The above table shows that if the phase error is 1 per cent., the error in the deflection is always less than 1 per cent. of the full deflection, however low the power factor, and that in nearly all cases it is less than 1 mm. measured along the scale.

The accuracy secured in the new instrument can be precisely indicated by the value of the phase error. In one of the portable standard instruments this value was only 0·0077 for 50-~ circuits, so that the corresponding errors are given by the numbers in Table I. when multiplied by 0·77. In one of the switchboard instruments θ was found to be 0·012 for 50-~ circuits, corresponding with the figures in Table I. when multiplied by 1·2. The error of the electromagnet is due to the phase error represented by the ratio of resistance to impedance of the field coil (see *Journal*, vol. 36, p. 439). This ratio is about 0·4 per cent. for 50-~ circuits. Two distinct ways have been found precisely to compensate the total phase error of the instrument for circuits of a fixed frequency. These methods have been amply tested and verified, but they have not yet been embodied in the commercial instruments.

The voltmeter is naturally less subject to error than the wattmeter, since the voltmeter is essentially the same as a wattmeter used on circuits of fixed power factor equal to unity. The deflection for a given voltage for a range of frequency of 3 to 1 does not vary as much as 0·5 per cent.

In confirmation of the above statements the tests indicated in Table II. below are given. They relate to a comparison of one of the iron-cored wattmeters (I.C.W.) with a standard Mather-Duddell instrument (M.D.W.). The current A was passed through (1) the current coil of the M.D.W., (2) the quadrature transformer of the I.C.W., and (3) a non-inductance load of lamps. It was obtained from a pair of slip rings of a small rotary converter run from the direct-current side, the voltage V_1 being approximately in phase with A. Another pair of slip rings gave a voltage approximately in quadrature with V_1. These were joined to the primary of an equal ratio transformer, the secondary voltage V_2 of which was about equal to V_1 in magnitude and also approximately in quadrature with it. Since the voltages V_1 and V_2 were electrically separate, they could be joined in series to produce a voltage V differing in phase from A by about 45°. By means of a reversing switch V could be made either the vector sum or the vector difference of V_1 and V_2. In the former case the voltage V was leading and in the latter case was lagging in reference to A. The pressure coils of the two wattmeters were put across mains at voltage V. The wattmeters were read carefully, and observations were taken alternately for leading and lagging voltages. The watts were obtained from the readings of the M.D.W. which had been previously standardised on a non-inductive load, using the same ammeter and voltmeter as were afterwards employed for the tests in Table II., the power factor $\cos\phi$ being obtained from the readings of the same instruments. The frequency of the circuit was 51 ~.

TABLE II.

Voltage.	V.	A.	M.D.W.	I.C.W.	Watts.	Cos ϕ.	Tan ϕ.
$V_1 + V_2$	120	19·8	66·6	65·4	1,550	0·652	—
$V_1 - V_2$	119	18·8	65·2	65·0	1,515	0·676	—
$V_1 + V_2$	122	19·4	66·3	65·0	1,540	0·650	—
$V_1 - V_2$	121	18·7	65·2	65·2	1,515	0·670	—
$V_1 + V_2$	—	—	66·45	65·2	—	0·651	+ 1·167
$V_1 - V_2$	—	—	65·20	65·1	—	0·673	— 1·099

The numbers given in the last two lines are the means of the tests for leading and lagging voltages. From these it appears that the readings of the M.D.W. corresponding with a reading of 65·2 of the I.C.W. in the two cases are 66·45 and 65·30.

Hence if the phase error is θ we have—

$$\frac{66{\cdot}45}{65{\cdot}30} = \frac{1 + 1{\cdot}167\,\theta}{1 - 1{\cdot}099\,\theta},$$

and the value of θ works out to be 0·77 per cent. Such value compares well with that calculated from the data of the wattmeter. The ratio of the resistance of the electromagnet winding to its impedance was measured as 0·385 per cent. at 50 $\sim$ or 0·378 per cent. at 51 $\sim$. The self-induction of the secondary of the quadrature transformer was 0·882 millihenry and the resistance of the moving coil circuit 82·8 ohms, so that the ratio of reactance to resistance at 51 $\sim$ works out to be 0·34 per cent. The sum of 0·378 and 0·34 is 0·72, comparing well with 0·77, the number measured. The quadrature transformer used was ironless, so that no allowance has to be made for any phase error due to hysteresis.

Phasemeters.—The theory and modes of calibration of phasemeters have been already discussed by one of the present writers (*Phil. Mag.*, vol. 11, p. 81, 1906, and *Electrician*, vol. 56, p. 760, 1906), and it has been shown that the phasemeters in general are much more accurate instruments on balanced loads than they are usually credited with being; in fact, phasemeters for multiphase circuits, if properly calibrated, are all alike in normal action, and differ only in liability to disturbances. Various makes differ, not in electrical, but in mechanical properties. The actual errors arising in working are due to causes quite apart from the electrical action of the instrument, being due to friction when the deflecting forces are weak, or to the influence of stray fields, or to the

want of balance of the circuit currents. In the instruments here described the moving coil is perfectly shielded by the iron, and if this coil is out of proper position the rectifying forces brought into action are strong, so that errors due to the first two causes do not arise. All phasemeters are equally subject to error when used on unbalanced loads. A similar error arises in measuring the power of a 3-phase circuit by the single wattmeter method. The error which arises from such want of balance is determined simply by the ratios of the three currents in the mains, and is not dependent on the instrument employed. It is the same for all wattmeters and for all phase-

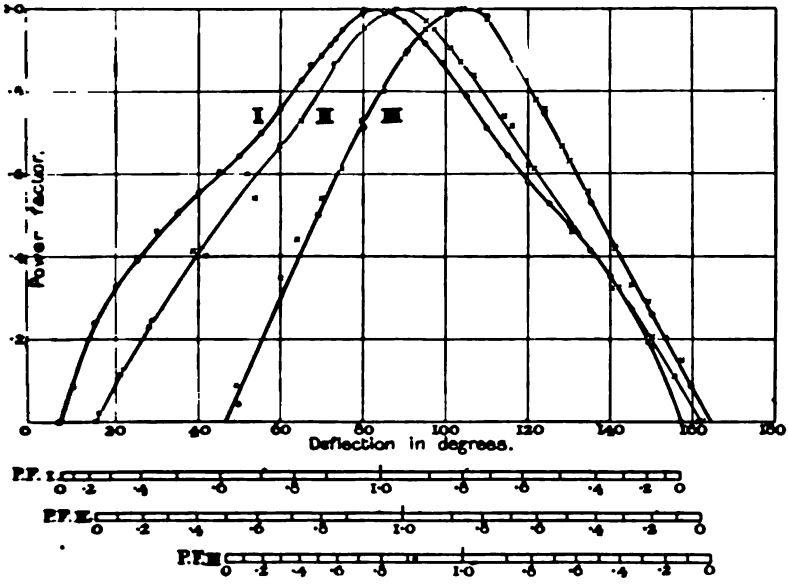


FIG. 23.

meters, however good or however bad they may individually be. It is not serious except for low power factors and for badly balanced loads.

In the design of the phasemeters here described a great deal of attention has been devoted to the production of suitable scales. Special difficulties arise in these instruments owing to the irregularities in the magnetic field due to the slots in the stampings bounding the air-gap. That these difficulties have been successfully overcome is shown in the curves of Fig. 23, connecting the deflection of the instrument (in degrees) with the corresponding value of the power factor. Three curves are shown for the same instrument for different modes of connection with the mains. In order clearly to separate the curves these have been arbitrarily shifted along the scale of degrees. The shift of zero corresponding with curves 1 and 2 is not known,

because the scale of degrees was changed between the two calibrations; but as regards curves 2 and 3, a reading of 140° for curve 3 denotes the same position of the pointer and moving coil as one of 120° for curve 2. The first two curves were obtained by the direct-current method, and the third by alternate-current tests. The field coils were the same, and were star connected in all three cases, but the most important of the three coils was joined up in one direction for curve 1, and in the opposite direction for curves 2 and 3. The calibration for curves 1 and 2 was determined from measurements on the currents actually flowing through the instrument coils. Curve 3 represents the action of the instrument when the coil currents were produced from the secondary circuits of two very small experimental transformers, the primaries of which were traversed by two currents representing those in the mains. The three scales of power factor $P F_1$, $P F_2$, and $P F_3$ are shown at the bottom of the figure, and it will be seen that the scale markings corresponding with curves 2 and 3 are regularly spaced. Numerous tests made at different times have proved that the alternate-current and direct-current modes of calibrating these instruments yield the same result. The tests shown by Fig. 23 are not given as any confirmation of this. The curves apply to the same instrument when connected to the mains in different ways. The tests for curve 3 consisted of two sets of observations taken at frequencies of 80 and 50 $\sim$ per second. These two sets of tests are distinguished by using different signs on curve 3, and incidentally show that the action of the phasemeter is independent of frequency.

If reference be made to the paper on the "Theory of Phasemeters" (*Phil. Mag.*, January, 1906), it will be seen (from equations 3, 4, and 5 on pp. 84, 85), that if $\mathbf{A}_1$ and $\mathbf{A}_2$ are two of the currents through the windings of one system of coils of the phasemeter, and if $\mathbf{V}$ be the current through the coil of the other system, the forces on the moving system will be balanced for a deflection x when—

$$\frac{\text{Mean product of } \mathbf{V}\,\mathbf{A}_1}{\text{Mean product of } \mathbf{V}\,\mathbf{A}_2} = \frac{\overline{\mathbf{V}\,\mathbf{A}_1}}{\overline{\mathbf{V}\,\mathbf{A}_2}} = \rho,$$

where ρ is a quantity which for any particular instrument depends solely upon the deflection x of the moving coil. Thus the deflection of the pointer depends simply upon the ratio of the two watt products $\overline{\mathbf{V}\,\mathbf{A}_1}$ and $\overline{\mathbf{V}\,\mathbf{A}_2}$. The phasemeter indicates power factor indirectly, but always measures by a single deflection the ratio of two watt products such as those frequently observed for the measurement of power factor from the readings of two wattmeters, or from successive readings of one such instrument. If there is any error in estimating the power factor from such a ratio, such an error will be common to all these methods, which are essentially the same except in the matter of relative convenience. Phasemeters, like ohmmeters, are instruments which really measure a ratio.

So far as theory and calibration are concerned, it does not matter whether the main currents are those actually used in the instrument

coils, or whether the latter are produced by the former through the operation of suitable transformers. If the transformers act correctly there will always be a particular deflection for each value of the ratio $\overline{A_1 V}$ to $\overline{A_2 V}$; so that if the instrument circuits are connected up in the special way in which they are to be used in practice, the currents A_1, A_2 and the voltage V used for calibration purposes may be produced in any convenient manner for determining the scale. The most convenient method in practice is to take the currents A_1 and A_2 from two independent secondaries of a transformer whose primary is subjected to the voltage V. It is easy to arrange for A_1, A_2, and V to be in essentially the same phase, and the ratio ρ is then simply that of the currents A_1 and A_2 as read by two ammeters. It only then remains to mark the deflection with the numerical value of the power factor corresponding with the ratio ρ observed. This value will be $\cos\phi$, where ϕ is such an angle of lag in actual working that the line currents A_1 and A_2 and the moving-coil current due to the line voltage will correspond with the same value of ρ as that observed in the calibration tests.

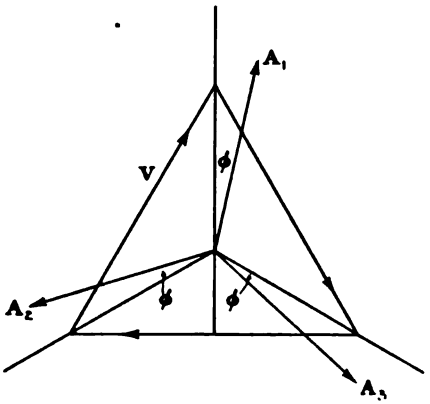


FIG. 24.

The real calibration of the instrument consists in determining by any convenient method the ratio ρ corresponding with each deflection x. The scale marking then depends on the interpretation to be given to ρ, and this interpretation will vary with the instrument connections, to the multiphase circuit, governing the magnitude and phase relations of the currents A_1, A_2, and the moving-coil current V in actual working.

As an example, if A_1 and A_2 are the currents in two of the mains of a 3-phase system, and if V is the voltage across these two mains applied through a high resistance to the moving coil of the phasemeter, then for balanced loads of power factor $\cos\phi$ it will be seen from Fig. 24 that the ratio of $\overline{A_1 V}$ to $\overline{A_2 V}$ will be numerically that of $\cos(30-\phi)$ to $\cos(30+\phi)$ but opposite in sign.

We shall thus have—

$$-\frac{\cos(30-\phi_1)}{\cos(30+\phi_1)} = \rho_1,$$

where ρ_1 is the value of the ratio observed in the calibration test for the deflection x which is to be marked $\cos\phi_1$.

Again, if the above case be varied by applying the voltage **V** to the moving coil through a condenser instead of through a non-inductive resistance, the moving-coil current will be in quadrature with the voltage **V**, and a little consideration will show that we then have—

$$+\frac{\text{Cos}\,(60+\phi_2)}{\text{Cos}\,(60-\phi_2)}=\rho_2,$$

and the deflection x to be marked $\cos\phi_2$ is that corresponding with ρ_2 as given by this formula.

From each such formula it is easy to plot a curve connecting $\cos\phi$ with ρ, and this curve can be conveniently used in the calibration tests. In most of the cases likely to arise it will be found that one or other of the above two formulæ (with proper sign for ρ) is applicable to the calibration tests. Inverting the value of ρ merely amounts to changing the sign of ϕ, so that it is convenient always to make ρ less than unity by dividing the smaller by the greater of the two quantities, the ratio of which is ρ. It is always necessary to know when ρ is to be taken positive and when negative, and this can only be predicted from a careful consideration of the vector diagram in each case; but in actual calibration no difficulty arises, for unless the proper sign be attributed to ρ the values of $\cos\phi$ read off from the curve are evidently wrong.

The numbers given in Table III. below enable the curves connecting ρ with $\cos\phi$ to be readily plotted for each of the above two formulæ. The curve for ρ_1 is well known and is often used for the determination of power factor by the two-wattmeter method.

TABLE III.

±	Value of Cos ϕ_1.		Value of Cos ϕ_2.	
	For ρ_1 ±	For ρ_1 ∓	For ρ_2 ±	For ρ_2 ∓
0·0	0·500	0·500	0·866	0·866
0·1	0·577	0·431	0·904	0·817
0·2	0·654	0·358	0·933	0·756
0·3	0·731	0·297	0·954	0·682
0·4	0·802	0·241	0·971	0·596
0·5	0·866	0·189	0·982	0·500
0·6	0·918	0·143	0·989	0·404
0·7	0·951	0·101	0·994	0·292
0·8	0·982	0·064	0·998	0·188
0·9	0·996	0·030	0·999	0·088
1·0	1·000	0·000	1·000	0·000

APPENDIX.

Note 1.—Summation Wattmeter.

A wattmeter to measure the total output of a set of generators would often prove useful in cases where, owing to the sectionising of busbars and feeder circuits, it is not possible or convenient to place a transformer so that its primary is traversed by the total current. The new instruments here described can be conveniently used under such conditions. One indicator is required, and the same number of quadrature current transformers as there are circuits in parallel. The wattmeter connections are shown in Fig. 25.

G_1, G_2, G_3 are the generators each connected to the busbars through a double pole-switch and the primary of a quadrature transformer T. In each case the current through the primary coil generates an electro-

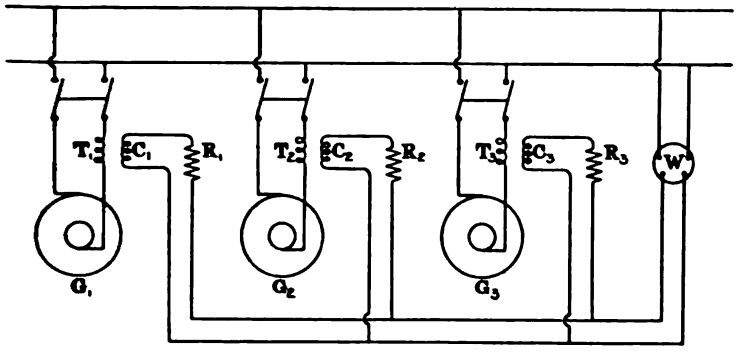


Fig. 25.

motive force e in the secondary coil, this coil being connected through a resistance R to two leads running to the moving coil of the wattmeter W. This moving coil will have a resistance which is low in comparison with the resistances R_1, R_2, R_3. These latter must all be adjusted so that the wattmeter reads correctly in each of the cases for which there is only one generator in action. The adjustments for R_1, R_2, R_3 will be almost independent of each other under the conditions assumed. If the resistances are properly adjusted the wattmeter will read correctly whatever the number of generators working in parallel. This follows from the fact that the current C through the moving coil is at any instant given by the equation—

$$C = C_1 + C_2 + C_3,$$

where the currents forming the parts of C are such that—

C_1 is calculated assuming $e_2 = e_3 = 0$.
C_2 „ „ $e_3 = e_1 = 0$.
C_3 „ „ $e_1 = e_2 = 0$.

The deflection of the wattmeter depends upon the mean value of the product of the field strength **F** and the moving-coil current **C**, but—

$$\mathbf{FC} = \mathbf{FC}_1 + \mathbf{FC}_2 + \mathbf{FC}_3,$$

and if the values of R_1, R_2, and R_3 have been so adjusted that the wattmeter reads correctly for each generator acting alone, it will also read accurately when two or more are acting together.

To test the above a standard wattmeter, with constant 20 watts per division, was used to measure the true power supplied to two loads in parallel. The currents $\mathbf{A}_1$ and $\mathbf{A}_2$ of the loads, and the voltage **V** of the mains were read by hot-wire instruments, these being only approximately accurate, but sufficiently so to indicate the conditions of test. The summation wattmeter under test was connected up in a manner similar to that shown in Fig. 25, so that its moving coil formed the common portion of the secondary circuits of two quadrature transformers, the primaries of which were traversed by the currents $\mathbf{A}_1$ and $\mathbf{A}_2$. The pressure coils of the two wattmeters were joined across the mains at the same points, and the current coil of the standard instrument was traversed by the sum of the two branch currents $\mathbf{A}_1$ and $\mathbf{A}_2$. The load $\mathbf{A}_2$ was in all cases non-inductive and consisted of banks of lamps. This was also the case for the load $\mathbf{A}_1$ except for the last two tests, in which choking coils were used to make the load inductive. A carbon resistance placed in the main circuit served as a fine adjustment to bring the reading of the standard wattmeter to 95 divisions in all cases. The corresponding readings of the summation wattmeter for different magnitudes of **V**, $\mathbf{A}_1$, and $\mathbf{A}_2$ are given in Table IV.

TABLE IV.

Test.	V.	A_1.	A_2.	Readings of Wattmeter.	
				Standard W.	Summation W.
1	91·0	0	20·8	95	94·7
2	91·0	20·6	0	95	95·1
3	91·0	9·0	11·7	95	94·8
4	93·5	13·8	10·7	95	95·0
5	94·5	9·9	17·9	95	94·8

The two first tests merely serve to show the correctness of the adjustment of the resistances of the secondary circuits of the transformers (43 ohms for one and 103 ohms for the other, exclusive of the resistance of the moving coil and fuse amounting to 16 ohms). The last three tests show that the summation wattmeter acts correctly as

closely as it was possible to read the instruments (95 divisions on the standard instrument measured only about 5 in. on the scale). The frequency of the current was about 50, and the power factor of the load A, in test No. 5 was only about 0·2.

Note 2.—Neutral-point Reactance Coil for Shunt-magnet Wattmeters.

A small transformer core with closed magnetic circuit is twin wound with two equal windings of n turns each of resistance r. These two windings are put in series, and the ends are joined to mains 1 and 2 at potentials V_1 and V_2. The potential of the junction of the two coils is P, and, on ordinary transformer principles, this potential P is half-way between V_1 and V_2 at every instant. The field-magnet coil of the wattmeter is joined to the junction P, and to the third main at potential V_3. The quadrature transformer QT of the wattmeter W

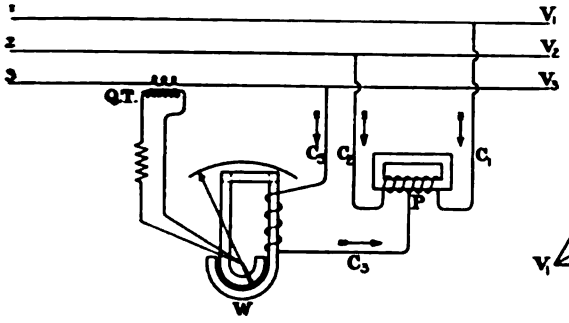


Fig. 26.

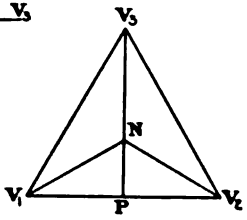


Fig. 27.

is placed in the third main as shown in Fig. 26. All the potentials are reckoned from that of the neutral point N as a zero.

The vector diagram is shown in Fig 27.

If the currents flowing to the point at potential P be C_1, C_2, and C_3; if ρ be the resistance, m the number of turns, and M the magnetic flux through the core, of the electromagnet coil; and if F be the flux through the core of the auxiliary transformer, we have—

$$V_1 + V_2 + V_3 = 0$$
$$C_1 + C_2 + C_3 = 0$$
$$V_1 - P = r C_1 + n \dot{F}$$
$$V_2 - P = r C_2 - n \dot{F}$$
$$V_3 - P = \rho C_3 + m \dot{M}.$$

Hence—

$$2 V_3 - (V_1 + V_2) = 2 \rho C_3 - r (C_1 + C_2) + 2 m \dot{M},$$
$$\text{or} \quad 3 V_3 = (2 \rho + r) C_3 + 2 m \dot{M},$$
$$\text{or} \quad 1{\cdot}5 V_3 = \left(\rho + \frac{r}{2}\right) C_3 + m \dot{M},$$

or the flux in the instrument magnet will be exactly one and a half times that which would be produced by applying to the magnet coil the voltage V_3 between the third main and the neutral point, provided the resistance of the field coil be considered increased by the parallel resistance of the two coils of the auxiliary transformer. The reading of the wattmeter, as standardised on a single-phase circuit, must be doubled to denote the power of the mains. It is found easy to construct a suitable small auxiliary transformer such that the parallel resistance of its windings is a small fraction of the resistance of the field-magnet coil.

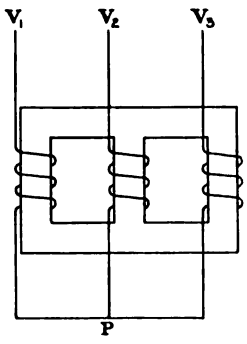


FIG. 28.

It is also possible to construct a true neutral-point reactance coil by assembling magnetic stampings suitable for a small 3-phase transformer, so as to form three similar cores magnetically connected in parallel as indicated in Fig. 28. Around each core is wound a coil of n turns having a resistance r. Three corresponding ends of these coils are star connected at P, the other ends being connected to the three mains at potentials $\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{V}_3$. If $\mathbf{C}_1$, $\mathbf{C}_2$ and $\mathbf{C}_3$ are the coil currents flowing to the point P ; if $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$ are the core fluxes, and if the potential of P be denoted by $\mathbf{P}$ we have—

$$\mathbf{V}_1 - \mathbf{P} = r\mathbf{C}_1 + n\dot{\mathbf{F}}_1$$
$$\mathbf{V}_2 - \mathbf{P} = r\mathbf{C}_2 + n\dot{\mathbf{F}}_2$$
$$\mathbf{V}_3 - \mathbf{P} = r\mathbf{C}_3 + n\dot{\mathbf{F}}_3.$$

Also, if the field coil of the wattmeter be connected between the third main and the point P, we have as before—

$$\mathbf{V}_3 - \mathbf{P} = \rho\mathbf{C} + m\dot{\mathbf{M}},$$

where $\mathbf{C}$ is the current in the field coil.

The conditions of continuity are—

$$\mathbf{C} + \mathbf{C}_1 + \mathbf{C}_2 + \mathbf{C}_3 = 0$$
$$\mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 = 0,$$

and we also have—

$$\mathbf{V}_1 + \mathbf{V}_2 + \mathbf{V}_3 = 0.$$

By adding the first three equations and using the last three we obtain—

$$-3\mathbf{P} = r(\mathbf{C}_1 + \mathbf{C}_2 + \mathbf{C}_3) \text{ or } \mathbf{P} = \frac{1}{3}r\mathbf{C},$$

whence—

$$\mathbf{V}_3 = \left(\rho + \frac{1}{3}r\right)\mathbf{C} + m\dot{\mathbf{M}},$$

thus the flux **M** of the electromagnet is exactly what would result from applying to the field coil the voltage V_3 between the third main and the true neutral point, provided the resistance ρ of this coil be increased by the parallel resistance of the three windings of the choking coil.

By the employment of such a reactance coil it is possible to use a single wattmeter to measure in succession the power corresponding with each phase of a 3-phase circuit. A quadrature transformer is needed for each of the three mains, and a light 2-pole 3-way switch similar to that shown in Fig. 10. However badly balanced the main currents may be, the true power of each phase can be measured, and the wattmeter may be normally left connected with that phase which best represents the total power supplied to the load.

Discussion in London.

Mr. S. Evershed: It is my privilege to be the first to congratulate the authors on the progress they have made in developing the shunt-magnet instrument. They have been at work on this series of instruments for nearly four years; I have watched their progress with the greatest interest, and I heartily congratulate them on the results they have achieved by their novel mode of employing iron in measuring instruments. One of the great drawbacks with iron is, of course, hysteresis. With an alternating-current instrument that disappears, but all sorts of other difficulties arise, and have remained until now practically unsolved. I am old enough to remember the time when one was trying to develop an ammeter working by means of a coil acting upon a piece of soft iron, in the days when it was hardly possible to find an ampere to measure. I certainly had a great deal of faith, for I believed it might be possible to discover an iron which had no hysteresis. I actually found one text-book which told me that a certain variety of magnetite which existed in some remote part of Italy had no hysteresis, or as they called it in those days, no retentivity. With some difficulty I obtained a small piece of this mineral, and only after paying a large sum for it did I discover that it had about as much coercive force and hysteresis as very bad cast iron. Since then I have had very little faith in text-books. I then set to work on the basis that the reason for hysteresis was the molecular friction in the iron. I believe I also had some authority for that from the text-books. I thought if I could dissolve some iron in a fluid it would have no hysteresis. After a great deal of trouble, by means of an electrolytic method I dissolved some iron in mercury. I found the fluid amalgam was as much affected by hysteresis as any ordinary piece of soft iron—rather more so if anything—and it also had the disconcerting habit of spontaneous combustion, which left me with a little black oxide of iron and a quantity of pure mercury. Since those old days Professor Ewing has made his exhaustive research on the subject, and we know now that wherever there are particles of

Mr. Evershed.

Mr. Evershed.

iron there must be hysteresis, because it is due to the proximity of magnetised particles to each other, and not due to any friction in the iron itself.

I must confess that in reading the paper I felt a good deal of difficulty in understanding some of the demonstrations and explanations. One feels that perhaps too many subjects are touched upon, so that no one subject is dealt with exhaustively. The authors hardly seem to me to have quite come to grips with the subject of the wattmeter itself, and one rather wishes they had devoted the whole of the paper to the wattmeter and left the other instruments for some other occasion. I notice that they pass over one point very lightly. I should very much like to hear them explain how a certain difficulty has been got over, and that is the effect of current induced in the moving coil circuit by the induction of the shunt magnet. I think they refer to that current as the "induced current." Of course all the currents in the moving-coil circuit are induced, but let us for the moment call the current induced in the moving-coil circuit by the shunt magnet the "induced current." That current should be in quadrature with the induction, and therefore have no torque on the moving coil. But the induced current has a very considerable strength. I estimate, very roughly, that it is something of the order 18 milliamperes. Now 18 milliamperes, when the working current in the moving-coil circuit is only about 4 milliamperes, seems at first sight rather alarming, and so it is until we remember that it is out of phase with the induction and should not do anything towards altering the deflection. But the self-induction of the moving-coil circuit is by no means negligible, and hence that 18 milliamperes must have a component in phase with the induction of the shunt magnet, which may cause a considerable error if the same wattmeter was used for measuring power at very different voltages. Possibly the authors do not intend their instrument to be used over a wide range of pressures, but one would very much like to know how the difficulty has been met, because in designing ordinary wattmeters of the dynamometer type the E.M.F. induced by the mutual induction between the two coils is a great nuisance, and it is one of the reasons why dynamometer wattmeters in which the moving coil is kept in the position where the mutual induction is zero (that is to say, torsion head wattmeters) really have an advantage over deflection wattmeters. There is a point referred to by the authors on page 237 which wants well rubbing in amongst the buyers of measuring instruments. The authors tell us there how the volt scale on the combined instrument is obtained from the watt scale by taking the square root. That is one of the things that buyers of instruments, including well-known engineers, never seem quite to realise. Generally speaking, any alternate-current instrument whatever must have a parabolic law. It does not matter whether it is an ammeter or a voltmeter, it is practically bound to have a parabolic law, and it must have the same kind of scale as the authors show on their voltmeter. That ought to be well understood by this time.

Mr. Eversbed.

I should like to refer to another instrument described in the paper, namely the phasemeter. It never seems to me that phasemeters are described in sufficiently simple language to enable people to get hold of the real principle involved, and in that respect I am afraid the paper does not really carry us much further. I do not know whether I am unusually dense in such matters, but I feel there is still room for another mode of explaining the action of a phasemeter. I will show how I regard the matter, and possibly that may assist some minds to grasp the principle.

The diagram shows a phasemeter connected to the mains M M of a single-phase circuit carrying a current C at pressure V. The phasemeter has two field coils A and B, fixed at right angles to

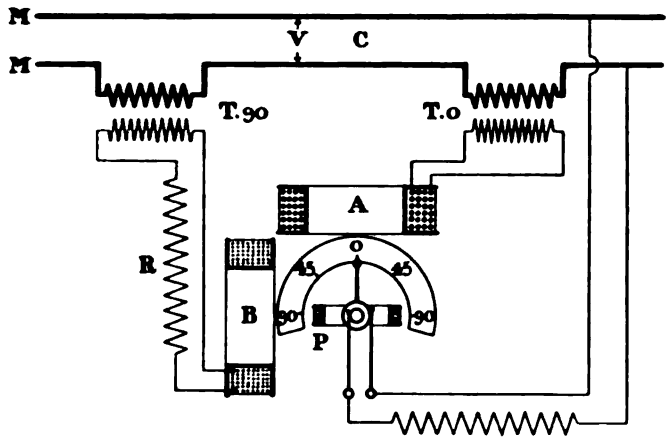


FIG. A.—Diagram showing the elements of a Phasemeter, or Power-factor Indicator, for Single-phase Circuits.

each other, and a pressure coil P which is free to rotate and take up any angular position in the field of the fixed coils. The pressure coil is in series with a non-inductive resistance, and is connected across the mains. The pressure current traversing P is therefore as nearly as possible in phase with the volts. Connection is made with P either by means of slip rings as indicated in the diagram or by means of flexible spirals of negligible torsion.

The coil A has a low-resistance winding connected to the secondary of a series transformer T.o. The secondary being short-circuited by the coil, the current in A is practically proportional to and in phase with C.

The coil B is connected through a non-inductive high-resistance R to the secondary of a quadrature transformer T 90, so that the current in B is practically proportional to and in quadrature with C.

To understand the action of this typical phasemeter we need not trouble about $\cos\phi$, nor need we make any vector diagrams. It is

Mr. Evershed.

only necessary to realise that any alternating current may be thought of and reasoned about as though it were made up of two components, one—the *working component*—exactly in phase with the volts, the other —the *idle component*—exactly in quadrature with the volts. Hence the current in A may be thought of as composed of a working component a and an idle component x; while the current in B is made up of a working component b and an idle component y. Now the current in the pressure coil P is in phase with the volts; it is therefore in phase with a and in quadrature with x. That is to say, component a will produce a torque on P, while x being in quadrature with the current in P, cannot produce any torque. Similarly in the case of the components b and y; but remembering that each of these has been turned through 90° by the quadrature transformer T 90, we see that b is in quadrature with the pressure coil current and cannot produce any torque, and y is in phase with the pressure current and will produce a torque on P. We may now dismiss the components x and b from our minds, since they cannot exert any torque on P, and concentrate our attention on the only acting currents, namely, the working component a in coil A, and the idle component y in coil B.

Consider what happens when V and C are exactly in phase—power-factor unity. Clearly y will be zero and a alone can act on P. The pressure coil must then turn upon its axle until it stands in the angular position shown in the diagram with its magnetic axis in line with the axis of A—in other words, in the position of maximum mutual induction. The point where the index stands must be marked o degrees if the instrument is to indicate the phase angle, or unity if it is to read power factor. Now imagine C to lag behind V. Component y being no longer zero will deflect P more or less according to the relative values of y and a. When the lag amounts to 45°, y and a will be equal, and if we have properly proportioned our windings on A and B, y and a will now produce equal fields acting with equal torques upon P. The pressure coil, then, urged by equal forces at right angles, will take up an angular position 45° from the direction of each of them. Increasing the lag still further, and remembering that with any constant value for C we decrease a as we increase y, we see that P will be deflected more and more until at last, when C is exactly in quadrature with V, component a will be zero and y alone will act upon P. Hence in that case the pressure coil will have been deflected through a right angle, and will stand with its magnetic axis in line with the axis of coil B. The point where the index now stands must be marked 90° for a phasemeter, or zero for a power-factor indicator.

If instead of a lag of C behind V we assume a leading current the same reasoning will apply, but the direction of y with regard to the pressure current being now reversed, the coil P will be deflected in the opposite direction, until when C is exactly a quarter period in front of V the index of the phasemeter will stand at 90° on the other side of o°, indicating a lead instead of a lag.

In an ideal phasemeter the coils A and B would be designed to

have uniform fields throughout the space occupied by the pressure coil, and in that case the deflection of P would not alone vary with the phase angle between V and C, it would be actually equal to the phase angle; and our scale would be simply degrees of arc. I have never seen an ideal phasemeter, but I do not know of any reason why the phasemeters one sees on switchboards should not be a good deal nearer the ideal than they are. Mr. Eversheds.

One other point—a serious one for instrument makers. The authors have shown us a wattmeter which is independent of frequency, independent of temperature, and independent of power factor, but no instrument in the world is independent of the buyer, who is exercising a very harmful influence at the present time on the design of instruments. He imagines that an electrical instrument is a thing in which there are a few pieces of brass put in by the instrument maker, and perhaps some more brass added by the sales manager. Let him abandon that conception if he wants a good instrument. If a buyer wants a first-rate instrument, such as the authors have shown us this evening, he must learn to pay for it.

Professor ERNEST WILSON: Having gained a little experience in the working of Dr. Sumpner's wattmeters I can give a few practical points in regard to it. But before doing so I should like to refer to the diagram, which illustrates a theoretical problem in connection with these wattmeters. Professor Wilson.

Fig. B is a diagrammatic representation of Dr. Sumpner's wattmeter, which depends for its action upon the equation—

$$\frac{1}{T}\int_0^T VA\,dt = \frac{1}{T}\int_0^T \left(\int_0^t V\,dt\right)\frac{dA}{dt}\,dt;$$

where V is the voltage, A the amperes, and T the periodic time. This equation is true for all frequencies and is independent of wave-form. It is illustrated by the curves in Fig. B.

The wattmeter represented in Fig. C was devised by one of my old students (Mr. W. H. Wilson) and is of the electrostatic type.* As shown, the moving system of the electrometer (Q) is connected to the ends of a non-inductive resistance (R) which is in series with a condenser (K) across the supply mains. The quadrants of the electrometer are connected to the terminals of the secondary circuit of a quadrature transformer (Q T).

The action of this instrument depends upon the equation—

$$\frac{(2\pi f)^2}{T}\int_0^T VA\,dt = \frac{1}{T}\int_0^T \left(\frac{dV}{dt}\cdot\frac{dA}{dt}\right)dt;$$

where f is the frequency. This equation is illustrated by the curves in Fig. C, and a comparison with those in Fig. B shows that provided V

* British Patent No. 26,512, 1905.

Professor Wilson.

and A are sine functions of the time the two wattmeters have equivalent quantities impressed upon them for torque production, namely, $\int V\,dt \times \frac{dA}{dt}$ in the one case and $\frac{dV}{dt} \times \frac{dA}{dt}$ in the other. It is easily shown that the above equation only holds strictly for sine curves, and it will be seen that it involves the frequency squared. Should, however, one of the differentials be replaced by the corresponding integral, the wattmeter would at once become independent of frequency and wave-form.

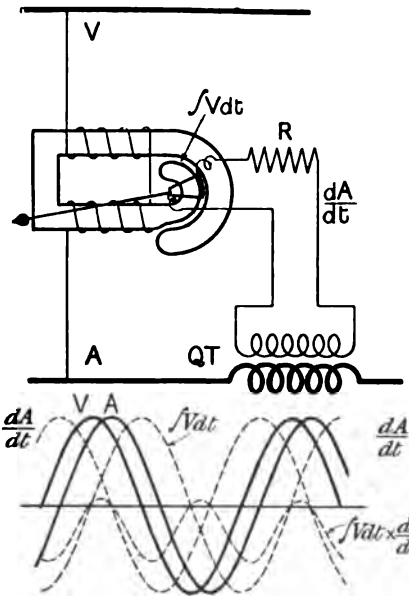


FIG. B.

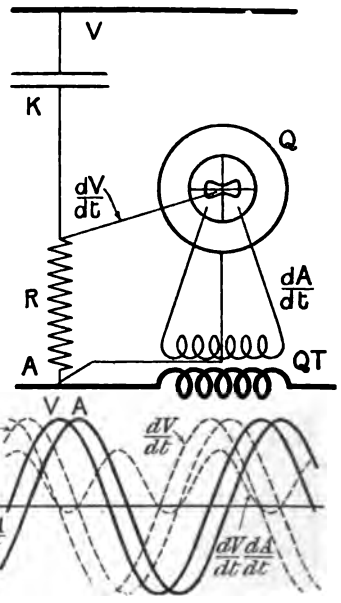


FIG. C.

I think Dr. Sumpner is to be congratulated because he was able to apply his knowledge of mathematics to a problem without making any experiments at all, and the application of those mathematics convinced him that his instrument would be accurate when he made it. Therefore I think the younger members of the Institution ought to keep their mathematics well before them and look upon them as a very valuable tool which can be brought to bear upon problems in time of need.

I would like to emphasise the following points in connection with the working of the instrument:—

1. Comparing quadrature with current transformers, I would point out the safety with which the secondary circuit can be broken in the first case, but not in the second. A case in which this is important is

the measurement of 3-phase power when two transformers are employed and one instrument. Then, again, the simplicity of construction of the quadrature transformer and the ease with which experimental ones can be made is in its favour. Professor Wilson.

2. The combination of a wattmeter with a voltmeter is valuable, especially in the case of a portable instrument, and it may be noted that the range as a voltmeter can be easily varied by changing the capacity of the condenser.

3. The instrument is easily adapted for the comparison of capacities and mutual inductions, and readily lends itself to a variety of other measurements.

Mr. KENELM EDGCUMBE: I should like to differ from Mr. Evershed, and to say that I admire the paper almost more than I do the instrument. I think that in some respects the authors have been led by their enthusiasm for the virtues of this instrument to overlook those of others, say, the dynamometer-pattern wattmeter. For example, they speak several times of the fact that their instruments are free from disturbance by stray magnetic fields; but so, of course, is the astatic dynamometer—absolutely free. On the other hand, the quadrature transformer which forms an integral part of their instrument is, I should say, anything but free from disturbance. It is quite true that in Fig. 5 they show it surrounded by an iron core, presumably to shield it from the stray fields, but it seems to me that the shell might as well be placed round the current coil of the dynamometer. In that case the instrument would be quite as free from errors due to stray fields as this. Then, again, they very rightly point out the disadvantages attending the use of iron cores in the current coils of wattmeters, but they use an iron core, as I have just said, in their quadrature transformer, and, as far as I can see, it has just as bad an effect in the transformer as if it were transferred to the instrument coil; in fact, it seems to me to be merely transferring the errors from the instrument to the transformer. Mr. Edgcumbe.

I am very glad to see that the authors inveigh against the indiscriminate connection of any number of instruments to one transformer. That is a practice which I think all instrument makers will agree with me in discouraging. I do not know whether I would go quite as far as they do in saying one ought to connect *nothing* to a transformer but the wattmeter. If the transformer is of fair size (say, 500 or 1,000 ampere-turns), there is no objection to connecting an ammeter or even an induction relay on to it. One of the chief offenders in this connection is, I think, the solenoid relay, in which not only is the back E.M.F. very high, but it varies largely with the position of the plunger or core.

I do not know that I can quite agree with their way of rating the instruments described on page 244. As far as I can see, in the case of a wattmeter designed for 10 amperes and 100 volts they would graduate the scale to 1,000 watts, that is to say, to the product of the maximum current into the maximum volts. I hardly think that is satisfactory, in view of the power factors which are met with in practice. I gener-

Mr. Edgcumbe.

ally recommend that the actual rating should be only half the maximum volt-amperes.

I notice that they express the accuracy as a percentage of the volt-amperes, whereas I think the accuracy in that case should be given as a percentage of the maximum scale reading in *watts*. The whole question of rating of wattmeters is, however, an important one, and I hope the Standards' Committee will deal with it.

On page 236 the authors describe what they call a "portable standard wattmeter." I should hardly have thought that the accuracy aimed at in these instruments was sufficiently high for standardising work. They speak of an error in the instrument itself of, I think, 0·5 of a degree as being good, and to this, I presume, has to be added the transformer error. This seems to me too high for a standard instrument. Then, again, I feel it is a great disadvantage, in the case of a standard wattmeter, not to be able to check it with direct current. It always seems to me essential in the case of a complicated instrument like a wattmeter—I do not mean complicated in itself, but one having to perform a complicated function such as measuring the instantaneous product of amperes and volts must be—it is essential that it should be capable of being easily checked with direct current.

I hope the authors will not think that, because I have criticised the instrument, it in any way detracts from my admiration of the paper, which simply teems with new and original ideas and suggestions applicable not only to these wattmeters, but to those of almost every kind.

Dr. Kapp.

Dr. G. KAPP: I wish to add my expression of admiration to the authors, not only for the paper, but also for the instruments. Instrument No. 1 happens to belong to a collection in my laboratory, and on testing it I found all the authors' claims for this type of wattmeter to be realised. No. 1 is one of the first instruments Dr. Sumpner has made and is not perfect, but these imperfections are not faults of system; they are merely faults of workmanship, and not great faults either. The air-space is not absolutely the same throughout the range. The consequence is that there is a slight variation in what should be the "constant," but this is only a matter of a few per cent. The instrument is independent of frequency and shape of wave, as I found when using it on different circuits. I think the principle which the authors have introduced of using iron in such instruments as voltmeters and wattmeters is a step in the right direction. There are very good iron-less voltmeters already on the market, but they take a large amount of power. When testing transformer iron for hysteretic loss, the total power with 10 kilogrammes of sample will only be from 20 to 30 watts, so that even a few watts absorbed by the voltmeter make a great difference in the reading of the wattmeter. For this reason it is advisable to put a key in the voltmeter circuits and take the watt reading when this key is not depressed. An instrument which in itself uses very little power may make such a precaution superfluous. It is a good feature of the authors' instrument that it may be adapted

to measure capacity. Theoretically we can take the capacity of any cable, short or long, by simply throwing on a certain voltage (the higher the better) and measuring the charging current, but in practice this method is not always applicable. The charging current may be too small to be measured accurately, and if the wave contains strong, higher harmonics, the capacity computed from current and E.M.F. measurements will be too large. By the authors' method even a small capacity can be measured with great accuracy, and the presence of upper harmonics cannot introduce any error since they affect the standard condenser in the same way as the cable to be measured. All that is required is that the E.M.F. does not alter in magnitude or shape between the two measurements. There is one remark made by Dr. Sumpner to which I take exception. He said that no wattmeter is accurate for unbalanced loads. If he meant to say that having an unbalanced load it is not correct to compute the total power by trebling the reading in one phase, this is self-evident, but I should not like it to go forth from here as a general statement that we are not able to measure power given to unbalanced loads. We have wattmeters which are accurate on unbalanced loads. I should like to remind the members of that method of measuring power which is due to Dr. Behn-Eschenburg, sometimes (but wrongly) called the Aaron connection, where two wattmeters are used to measure the total power in an unbalanced 3-phase load. That method is correct, but the wattmeters must not be placed so close together as to influence each other. If one attempts to build a duplex instrument on the Behn-Eschenburg principle with the two moving systems mechanically connected, certain errors are introduced from the stray fields, and then the instrument will not be very accurate. But recently Dr. Franke, of Messrs. Siemens and Halske, has designed a new wattmeter where no error occurs due to mutual influence; or, rather, the mutual influence is taken into account in the construction and calibration of the instrument. The new Siemens & Halske 3-phase wattmeter gives on one scale the total power quite independent of the distribution of the load between the three circuits. Dr. Kapp.

Dr. C. V. DRYSDALE: Every one must admire the instruments which have been shown so effectively, and the beautiful theory which underlies them. I will confine my remarks to the wattmeter as being the more interesting and valuable instrument. Apart from electrostatic and hot-wire wattmeters, we have been accustomed to two types of electromagnetic wattmeter—the dynamometer and induction types. How may the authors' instrument be described? At first sight it appears to be a dynamometer instrument on a new principle, as it has fixed and moving coils, but it differs in having an inductive shunt circuit and a quadrature transformer in the main circuit. When, however, we come to compare it with the induction pattern we are able at once to recognise the similarity. The comparison is best made by diagrams of the two types. Fig. D shows the simplest form of induction wattmeter, consisting of a metal disc and two magnets. The left-hand Dr. Drysdale.

Dr. Drysdale.

magnet S is wound with a shunt coil, and the flux induced by it is therefore approximately proportional to $\int V\,dt$. The right-hand magnet M is wound with a main coil, and in consequence induces a current in the disc proportional to $\frac{\partial C}{\partial t}$. This current crossing the field

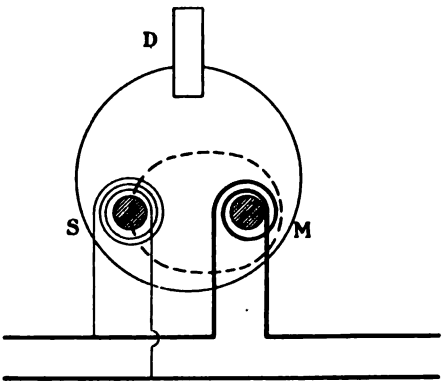


FIG. D.

due to magnet S produces a torque proportional to the mean product of $\frac{\partial C}{\partial t}$ and $\int V\,dt$, and it is easy to show that this is the same as mean C V or the mean power in watts, whatever the frequency or wave-form. Fig. E similarly represents the authors' wattmeter. The shunt magnet

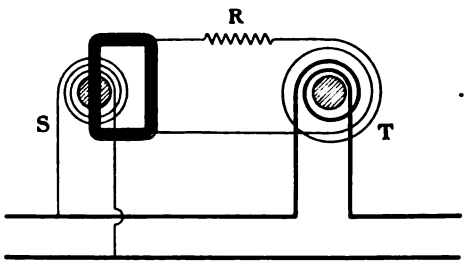


FIG. E.

on the left is identical in construction and function with that in the induction wattmeter, but in place of the disc a moving coil intersects its field. On the other hand, the "quadrature transformer" T on the right contains a main circuit, a divided core, and a secondary circuit, and the current induced in the secondary and moving coils is identical in phase and wave-form with that induced in the disc of the induction wattmeter by the main coil magnet. In fact, the authors' wattmeter is

an induction wattmeter in which the currents induced by the main coil, instead of being induced in and carried by the moving disc, are induced in a separate coil and taken through leads to the moving coil, and its theory is thus identical with that of the induction wattmeter. It may be termed an induction wattmeter with external induction. This immediately answers Mr. Evershed's difficulty as to the induction in the moving coil by the shunt magnet, which is identical in effect with the eddy currents induced in the induction wattmeter disc by the shunt magnet, and in that case simply increases the torque. In the authors' instrument these currents are not utilised. Dr. Drysdale.

It thus appears that the authors' wattmeter is nothing more than an old friend with a new face, and the moment this is realised it is possible to make comparisons and to appreciate the advance they have made. The simple induction pattern wattmeter can be made a very satisfactory instrument; in fact, I have tested a wattmeter of this type which shows absolutely no error on zero power factor, which is an extremely good performance. It appears that the authors, by having an external transformer and fine wire secondary, have gained in two respects: first, in being able to eliminate temperature variations by introducing a considerable swamping resistance R; and secondly, in being able to switch over from circuit to circuit, which has not hitherto been done with any electromagnetic wattmeter. They have lost in discarding the essential simplicity of the plain induction pattern instrument and introducing the complexities of moving coil and transformer as well as air damping, whereas, in the induction pattern, damping is easily effected by a permanent magnet D acting on the same disc.

Turning now to the comparison with the primitive or dynamometer wattmeter, there is one essential theoretical difference to which attention has already been called. In the dynamometer pattern of instrument, apart from inductive errors, the torque is directly due to the product of the potential difference V and current C, whereas in the induction pattern the action of the shunt field on the eddy currents induced by the main coil gives rise to a torque proportional to the mean value of $\frac{\partial C}{\partial t} \times \int V\,dt$. In the simplest case, that of sine-wave forms, $\frac{\partial C}{\partial t} = pC$ where $p = 2\pi\sim$ and $\int V\,dt = \frac{V}{p}$. In taking the product, therefore, the frequency is eliminated, which is generally true so long as the fields and induced currents are strictly proportional to the potential difference and current which induced them. This can only be true, however, over a certain range, as is evident from the fact that the instrument will give no indication on direct current, which is simply an alternate current of frequency zero. The current in the shunt coil will be different for different frequencies.

In my own form of deflectional instrument I have preferred to follow the simple dynamometer principle as far as possible, and it is easy to show that iron may also be used in this instrument provided that it is kept entirely in the main circuit, and that there is an air-gap

Dr. Drysdale.

bearing a definite proportion to the magnetic path in the iron. The advantage of this arrangement is that no question of lag due to resistance, which is a somewhat important matter in the induction wattmeter, has to be compensated for, and the instrument requires no adjustment. Fig. F shows a section of this form of wattmeter in which the main coils are wound like the fields of an iron-clad dynamo, and a moving coil of narrow or Ayrton Mather form is employed. Although I do not claim that this is necessarily better than the authors' instrument—and there is quite room for wattmeters both of the dynamometer and the induction type—I think it has the advantage of simplicity. I am glad that Professor Kapp has brought up the two-wattmeter method of measuring 3-phase power, and I am unable to understand why

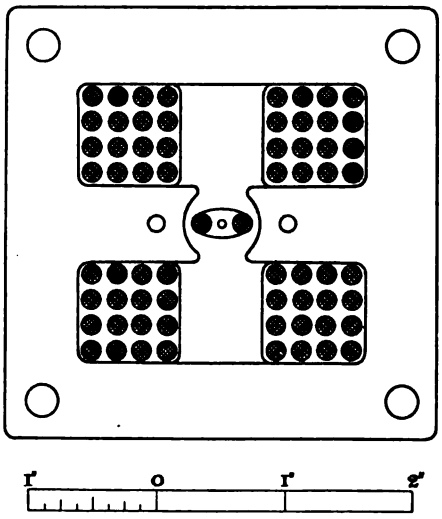


FIG. F.

manufacturers have not done more in the production of double wattmeters. Ever since my own first experience with wattmeters I have designed instruments of the double type, and in the form just described it is only necessary to have two similar systems at right angles, in which case the interference is practically nil.

In conclusion, I consider the method of measuring capacity introduced by the authors a most beautiful and practical one, and I feel sure that it has great advantages over nearly every other method. It, of course, can be equally well used with any other type of wattmeter if a choking coil is introduced into one of the circuits, but the fact that this method is independent of frequency and wave-form has been entirely established by the authors and is of the greatest value.

Mr. Irwin.

J. T. IRWIN: I should like to show the method of compensating for the errors in the wattmeter, to which Dr. Sumpner has referred in

his opening remarks. This method I brought to Dr. Sumpner's notice a short time ago, and he found on looking up his notes that it had also occurred to him. It is required to measure the power given to the circuit A B. The vector diagram shows the phases of the various quantities. V is the voltage across A B. C_1 is the main current in the circuit lagging behind V. R_1 and L_1 are the resistance and the inductance of the magnet coil. F is the flux in the magnet coil lagging nearly $\frac{\pi}{2}$ radians behind V, and inversely proportional to the frequency. C_2 is the current, directly proportional to the frequency, in the secondary of the quadrature transformer, which, owing to the inductance of its circuit being small compared with its resistance, I shall assume lags only $\frac{\pi}{2}$ radians behind C_1. In this case the angle between the flux and the secondary current is $\phi + \frac{R_1}{L_1 P}$, where ϕ Mr. Irwin.

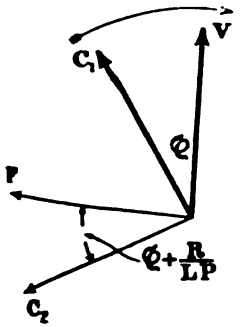


FIG. G.

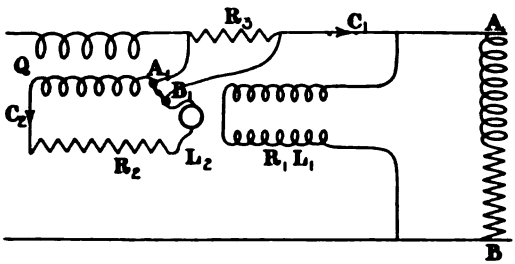


FIG. H.

is the angle between the primary current and voltage, and $\frac{R_1}{L_1 P}$ is the angle by which the flux falls short of being $\frac{\pi}{2}$ radians behind the voltage.

To make the angle between the flux in the magnet and the current in the secondary exactly equal to the angle between the primary current and the primary voltage it is necessary to advance the phase of the secondary current by $\frac{R_1}{L_1 P}$. To do this, the moving coil circuit is broken at A B and joined up to the end of the resistance R_3 in the main circuit.

If this is joined up in the right direction, there will be two E.M.F.'s in the secondary circuit M P C_1 and C_1 R_3, and the resultant E.M.F. is $\frac{\pi}{2} - \frac{R_1}{M P}$ radians behind the current in the main circuit, where M is the mutual induction of the two coils of the transformer.

Mr. Irwin.

When $\frac{R_3}{M\,P}=\frac{R_1}{L_1\,P}$ the wattmeter would be correctly compensated for the resistance of the magnet winding and would read correctly on any power factor or frequency.

Further corrections could be introduced to compensate for the small self-induction of the moving-coil circuit and for the iron (if any) in the quadrature transformer. Thus the total angle of lag of the current in the secondary circuit behind the flux in the magnet when there is no compensation is equal to—

$$\phi+\frac{R_1}{L_1\,P}+\frac{L_2\,P}{R_2}+\theta$$

where $\frac{L_2\,P}{R_2}$ is the angle of lag of the secondary current behind the secondary E.M.F., and θ is the angle of lag of the flux in the transformer behind the primary current owing to the hysteresis in the iron. If R_3, the resistance in the main circuit, is increased so that—

$$\frac{R_3}{M\,P}=\frac{R_1}{L_1\,P}+\frac{L_2\,P}{R_2}+\theta,$$

then the wattmeter will read correctly at any power factor at one particular frequency, and will be correctly compensated for the resistance of the magnet winding for any frequency. In addition, it will be partially compensated for the self-induction of the moving-coil circuit, and for the lag due to hysteresis at any frequency greater than, and over compensated for any frequency less than, the particular frequency chosen for exact compensation. For any practical frequency the phase error will be only a small fraction of the phase error when uncompensated, which Dr. Sumpner has shown can be made very small.

(*Communicated*): The great advantage of the Sumpner wattmeter is, that it can be easily adapted to measure the power in any circuit no matter whether the current is very large or very small, and in this is comparable with a moving-coil ammeter; in fact, it has an advantage over the moving-coil ammeter, in that the drop of voltage in the primary of the transformer decreases as the current increases. But the wattmeter has the serious disadvantage that it is not easily adaptable to measure the power in a circuit when the voltage is higher than that for which the magnet is wound. One cannot, as in the ordinary type of wattmeter, put a resistance in series with the pressure coil (or magnet coil).

It is necessary to introduce a transformer to reduce the pressure to that suitable for the magnet. If the magnet winding only very slightly loads the secondary of the transformer, then owing to the flux in the transformer being less than $\frac{\pi}{2}$ radians behind the primary voltage, the secondary voltage is less than π radians behind the primary, and there

will be another error introduced into the wattmeter, and this will be added to those already referred to. Mr. Irwin.

This error will be small, as the transformer will, of course, have a closed iron circuit. In an E.H.T. transformer, where the windings are kept a comparatively great distance apart, and the current taken by the magnet coil being a lagging one, the voltage on the secondary winding of the transformer may be more than π radians behind the voltage on the primary, and in this case the error is substracted from those referred to above.

In either case the method of compensation will enable an adjustment to be made that will practically wipe out all the errors in the instrument.

Mr. ALEXANDER RUSSELL (*communicated*): The authors' tests show that the accuracy of the instruments is sufficiently high for central station work, and they seem well adapted for switchboard use. As Mr. Evershed pointed out, there are still one or two little points in connection with the theory of the wattmeter and voltmeter that need to be elucidated, but I have no doubt that Dr. Sumpner will do this, and, if necessary, slightly modify the design of the instruments. Perhaps the authors are a little too enthusiastic about the advantages of shunt electromagnets. It is quite true that the eddy currents do not alter the total flux through the core of the electromagnet, but they alter its distribution, and this can lead to errors. In Fig. 7 the authors show the connections for their wattmeter on a balanced load. By a balanced load the electrical engineer usually means that the currents in the three mains are practically equal, and that the potential differences between the mains are also practically equal. Taking this to be the meaning of a balanced load, I am not prepared to admit that the sum of the instantaneous values of the three potentials of the mains is zero. If one of them were earthed, for instance, this would certainly not be true. In systems where we have an appreciable length of three-core cable and the fault resistance of each main is not very low the assumption is permissible and the method is correct, but the effect of want of balance of the potentials should be considered in the proof given in Note 2. The connections shown in Figs. 10 and 25 are exceedingly neat and instructive. The magnetostatic voltmeter is an instrument that will be useful in the lecture-room as well as on a switchboard, as it is such an excellent illustration of electrical principles. Its only practical limitation is that it will not read voltages on direct-current circuits, and voltages which are partly direct and partly alternating. The method of measuring capacity explained by the authors will prove valuable in practice, and it is more accurate than many more pretentious methods. I appreciate highly Dr. Sumpner's method of considering the theory of phase indicators. There are still, however, some outstanding difficulties. In Fig. 22, for example, a neat form of phase indicator for single-phase circuits is shown. Let us suppose that the applied wave is sine-shaped, and that the load on this circuit is a resistance, an inductive coil L and a condenser K, all Mr. Russell.

Mr. Russell. connected in series. Now when the capacity of the condenser is very small the instrument will indicate a leading power factor. As we gradually increase the capacity K of the condenser the power factor will increase, passing through its maximum value unity when $K = 1/(4\pi^2 f^2 L)$, where f is the frequency. For greater values of K the instrument will indicate a lagging power factor. It would be interesting to know how the instrument would behave if we carried out this experiment in exactly the same way when the applied voltage wave had harmonics of large amplitude. In this case the power factor can never be unity, but (taking an extreme case) let us suppose that its maximum value is 0·8. Then I have often wondered if the pointer of the instrument would jump from 0·8 leading to 0·8 lagging at a single bound, a phenomenon which seems to me to be physically impossible, or whether it would be very unsteady, or whether it would simply read wrongly. Exactly the same criticism applies to 3-phase indicators. I agree with Dr. Sumpner that ordinary phase indicators are of great use in practice, but with distorted waves their readings have to be freely interpreted. Dr. Sumpner several years ago pointed out the risks run when you draw too many vectors of periodic quantities (not obeying the sine law) in one plane. In Fig. 24 the vectors representing the three potential differences between the mains are in one plane, because the sum of the instantaneous values of these potential differences is always zero. Similarly the three vectors, A_1, A_2, and A_3, are in one plane. But are these two planes coincident? It seems to me that in graphical theory we have to consider not only whether vectors are in one plane, but also the relative positions of given planes.

Dr. Garrard. Dr. C. C. GARRARD (*communicated*): The authors state that the torque on the moving-coil system of their instruments for full scale deflection is 1·2 gramme-centimetres, and also that this is greater than that usually employed in the dynamometer or induction-type instruments. As far as my own information goes, however, this is not wholly correct. For the dynamometer-type instruments it is correct.

As regards the torque at maximum scale deflection, however, for induction instruments as made by Messrs. Ferranti, Ltd., these are as follows:—

Induction ammeters and voltmeters, 3–4 gramme-centimetres.
Induction indicating wattmeters, 2–3 gramme-centimetres.

One of the chief advantages of induction-type instruments is that one can obtain a large torque with them. This is of importance for switchboard instruments, as it means that all the parts can be made heavier and stronger, and capable of withstanding rough usage, which are very important points for such instruments.

Professor Ayrton. Professor W. E. AYRTON (*communicated*): I have read and re-read all Dr. Sumpner's papers, including the present one, several times. The history of the development of Dr. Sumpner's instruments is a

fascinating one because at the beginning the method of using iron in alternate-current metres seemed so hopeless if any approach to considerable accuracy was aimed at. But the survival-of-the-fittest principle has underlain all the trials and modifications of his meters, and their early reception by electrical engineers resembles the reception of the Darwinian theory by the world fifty years ago. The first contribution, which constituted his Inaugural Address as Chairman of the Birmingham Local Section in 1904, was mainly suggestive, and as a paper worthy of reading and discussion it observed that it might be possible successfully to use iron in alternate-current instruments. Professor Ayrton.

In 1906 he presented a further paper to the Institution, which was published in the *Journal* as an Original Communication. By that time people had become alarmed that his theories might be true. Later in 1907 he submitted another paper to the Royal Society, developing his ideas still further. Next, the General Electric Company took up the manufacture of his instruments, and now he finally brings before us the completed realisation of his production of four years' work.

As to the correctness of his theories and the commercial accuracies of his instruments, a test of them enables them to speak for themselves, they being, in fact, now able to speak for themselves, which is held by scientific people as being the climax of Darwinian development.

Mr. W. PHILLIPS (*communicated*): The first point that strikes one on looking at the general view of the instrument in Fig. 1 is the damping arrangement. Here, apparently, the designer has made a virtue of necessity in placing the vane at the end of a long pointer in order to balance the moving coil which is pivoted in a line with one side. This arrangement appears to me as one likely to give some trouble. Instruments are often very roughly handled in transit, and as the clearances between the damping vane and air chamber are necessarily small, it is not unlikely that the pointer may get sufficiently bent to cause the instrument to stick. Again, if only small overloads are suddenly applied to the instrument, or if the full load is suddenly put on the instrument a number of times, the pointer may bend sufficiently to cause the damping vane to stick, or at any rate to upset seriously the side balance of the moving system. Mr. Phillips.

With regard to the torque on the moving system, this is given as 1·2 gramme-centimetres, and one or two speakers, as well as the authors, have drawn comparisons between this and the torque that can be obtained on the dynamometer form of instrument. I can only speak of the dynamometer instruments of Messrs. Elliott Brothers' manufacture, and while agreeing that the usual value of the torque is in the order of 1·2 gramme-centimetres, I would say that in one pattern of switchboard dynamometer instrument the torque for 90° deflection is rather more than three times that given by the authors, and in their extra large dial station voltmeters of the dynamometer pattern the torque is nearly ten times that of the authors' instrument.

Mr. Phillips. With regard to the quadrature transformer, I think it is a matter for regret that it is necessary to employ such a device in connection with the wattmeter, at any rate for switchboard use. Although it may not be advisable to work trip coils in series with indicating wattmeters, I do not think there is so much objection with regard to relays and integrating wattmeter coils.

Speaking of 2- and 3-phase systems, there are very few power stations in the United Kingdom where the average power factor falls below 0·9 to 0·85, and the extra expense of the quadrature transformer, and, more important still, the cost of fixing this and running the additional instrument connections, to say nothing of the extra space required, is hardly warranted by the slight improvement, if any, in accuracy.

For high potential 3-phase circuits, it appears from the connection shown in Fig. 8 that the wattmeter will require not one extra transformer, but three, namely, one quadrature and two potential transformers. Usually the switchboard indicating wattmeters are worked off the integrating wattmeter potential transformers, but this will not be possible with the arrangement shown in Fig. 8.

With regard to the measurement of the output of a number of alternators in parallel, and also of total output, the arrangement shown in Fig. 10 can, by slight modification suitable to the type of instrument, be used also for the dynamometer form of wattmeter. Another point that is of considerable importance, particularly in the case of portable instruments, is the possibility of using them indifferently on a 50-~ or 25-~ circuit. Apparently it is not possible, or at any rate advisable, to use a 50-~ instrument of Dr. Sumpner's type on a 25-~ circuit. I would point out here that this is one of the advantages of the dynamometer pattern, that it can be used indifferently on a 50-~ or 25-~ circuit. This is particularly important for test sets, such as dynamo and engine builders require. The frequency for which machines are now generally built varies from about 25 to 60 ~, and it is necessary that the testing equipment shall cover this range.

I gather from the author's remarks on frequency variation under the heading of Magnetostatic Voltmeters, that their 50-~ instrument would either burn out, or at any rate overheat, if used on 25 ~. That the possibility of using a 50-~ instrument on a 25-~ circuit and *vice versâ* is a property not to be neglected, even in the case of a switchboard instrument, can best be illustrated by an actual case that occurred recently.

Some alternate-current dynamometer-recording voltmeters of Messrs. Elliott Brothers' make were ordered by a firm of engineers in Australia. On delivery it was discovered that a mistake had been made, and that 50-~ instruments had been ordered instead of 25-~. I was able to reply, in answer to a cablegram, that the instruments could equally well be used on a 25-~ circuit as for the 50-~ for which they were ordered.

As an illustration of the converse of the above, there is a switch-

board in a Central Station near London now supplying current at 50-~ controlled through the agency of dynamometer instruments originally installed when 25-~ was the frequency of supply, and this without the adjustment or removal of a single instrument from the switchboard. Mr. Phillips.

I will add nothing in connection with many other points of great interest, except that I have had phasemeters in use with iron-cored series magnets for some considerable time, and find that I can thereby greatly increase the torque, and therefore the robustness of the instruments.

Discussion at Birmingham, April 8, 1908.

Mr. A. M. Taylor: When these instruments were first shown by Dr. Sumpner various forms of electromagnet were used, including some placed in series with the main circuit. Do the authors still recommend this type, or do they possibly wish to forget having spoken of these on a former occasion? Mr. Taylor.

Mr. J. P. Kemp: Speaking as a central station engineer, we owe a great deal to the authors for the science and ingenuity which they have displayed in the construction of these instruments. I am especially interested in the wattmeter, and would particularly like to know whether they have given any attention to wattmeters of the integrating type. Also can we use existing current transformers when applying these instruments, or is it essential that we should use the particular type which Dr. Sumpner has shown us? In view of the very small amount of room available for instruments on modern switchboards, I should also like to know whether these instruments can be made up in the edgewise pattern, as this is practically the only possible type of instrument where room is a matter of consideration. Mr. Kemp.

Mr. J. D. Coales: Can Dr. Sumpner give some idea as to how much current can be taken from the secondary of a quadrature transformer without appreciably reducing the phase difference between the primary and secondary currents below 90°? I have tried the experiment of connecting the main coil of an ammeter transformer in series with the current coil of a wattmeter, and the secondary winding to the pressure coil of the wattmeter. On sending current through the transformer the wattmeter gave a considerable reading, thus showing that the primary and secondary currents were in this case not in quadrature. The secondary winding of the transformer had several hundred turns, and the wattmeter pressure coil a resistance of several thousand ohms. Our thanks are due to Dr. Sumpner for the very clear explanation, in the introduction, of the fundamental differences between the properties of the shunt and series alternating electromagnet. Mr. Coales.

Dr. D. K. Morris: Dr. Sumpner has previously given an explanation of the action of his phasemeter, which appears to be more simple Dr. Morris.

Dr. Morris. than the theory now given. It is clear that a coil carrying alternating current and placed in a revolving field, but otherwise not subject to control, can only take up a position such that at the moment of maximum current flowing in the coil the field where the coil finds itself is zero. If the coil were in any other position, then it would naturally tend to be deflected into that position. This theory seems quite simple, but, as Dr. Sumpner does not give it, I should like to know if he regards it as unsound. I should like further to know if the indications of these phase indicators or power-factor meters depend upon the wave-form, so that their calibration would be erratic at certain particular phase indications.

Mr. Brew. Mr. WILLIAM BREW: The instruments described by the authors are of both switchboard and portable type, and, although it may be argued that little difference need exist in these two classes of instruments, in practice the duty expected of them may differ considerably. Taking first switchboard types of instruments such as are required by alternate-current stations working at extra high pressure, it is to be noted that the instruments of primary importance at the power station are those to record pressure of supply and units generated. Instruments of secondary importance are necessary to indicate current per phase on each generator and feeder. Auxiliary instruments are also essential for synchronising, indication of excitation, etc.

Other instruments such as power-factor indicators, idle-current ammeters, phasemeters, etc., are not generally essential except in those cases where the extended use of synchronous motor sub-stations permits of the power factor of the load being regulated within certain limits.

Even looking at the question of switchboard instruments from a purely commercial point of view, it is of great importance that the power station be equipped with good voltmeters and wattmeters, and since the cost of such instruments may naturally be expected to increase in due proportion to their reliability and accuracy, it is necessary to determine what variation from the truth is permissible in their indications. Under existing obligations as to the regulation of pressure and the necessity of arriving at, as far as possible, a true return of the units generated in any given time, the indications of these two instruments should undoubtedly be reliable within 1 to 2 per cent. under all working conditions. It is further to be borne in mind that both in the initial installation of each unit of generating plant, and also after any subsequent overhauling of these has been effected, it is often of the greatest importance to determine accurately the performance of the plant upon the usual basis of lbs. of steam per kilowatt-hour. Upon such measurements may depend bonus, payments, or heavy penalties to contractors, and hence extra expense should not be grudged if really reliable instruments can be obtained for this duty.

The wattmeters described by the authors are of the directly indicating type. The usual practice hitherto in the equipment of alternating-current stations has been to provide watt-hour meters upon

each generator, such instruments possessing the advantage of indicating at once the units generated in any given interval. The powerful and positive action of the wattmeters described by the authors, due to the fact that they are able to use iron in the construction of these instruments, and that they are unaffected by wave-form, frequency, etc., should, however, specially fit them for service as recording instruments or watt-hour meters, and as such they should cover an extensive field of usefulness. Mr. Brew.

As regards ammeters required for indicating amperes per phase on each generator, or the approximate share of the load when one or more units are running in parallel, the practical conditions are not so exacting, and consequently cheaper and less accurate instruments can generally be employed. The same remark holds good to probably a greater extent as regards ammeters upon feeder panels. An accurate and reliable type of synchroniser is, however, of great importance, and here again expense should not be spared to obtain a really serviceable instrument.

The application of measuring instruments to extra high-pressure switchboards, as sometimes carried out at present, is, from the station engineer's point of view, not altogether an unmixed blessing, the chief cause of uneasiness arising from the necessity of a number of high-pressure connections to busbars, the integrity of which the engineer cannot afford to endanger by the introduction of any source of breakdown which can possibly be avoided.

As an example of unnecessary connections, we may take the case where A tenders for a high-pressure switchboard, and includes in his tender instruments manufactured by B, often of foreign make. A makes his own switches, trip coils, and relays, together with suitable current and potential transformers for operating same. B's wattmeters and other instruments are specially designed to work in conjunction with potential and current transformers made by himself, and quite unsuitable for actuating the switchgear we have supposed made to the standard patterns of A, the principal contractor. The result is that a multiplicity of unnecessary high-pressure connections to the busbars is entailed, absolutely courting danger to life and breakdown. Standardisation with regard to such instrument transformers is most essential.

Associated with extra high-pressure supply at, say, 10,000 or 20,000 volts, it is almost impossible to prevent static discharges between some portions of the switchgear, insulators, etc., and the consequent production of ozone in greater or less quantities. The disastrous effect of ozone upon the rubber cable connections generally used for instruments has of recent years been proved in so many instances that it is idle to under-estimate the importance of avoiding such connections as far as possible upon every extra high-pressure switchboard, and it would appear that standardisation in this direction is also sorely needed.

The practice of some Continental firms who arrange instrument connections from one coil of the alternator at a pressure amounting to

Mr. Brew. only a small but definite sub-multiple of the working pressure has much to recommend it on the score of freedom from breakdown, and it may probably be more generally followed in the future by British manufacturers. Absolute continuity in electricity supply has now become of such vital importance in view of its numerous applications that it is hard to estimate the damage occurring commercially to an undertaking from any interruption in its supply.

Coming now to the portable alternating-current testing set described by the authors on page 236, this would appear to be a very desirable instrument for an alternate-current undertaking to possess. Such an instrument should prove of considerable value in the testing of watt-hour meters, reverse-current relays, alternate-current motors, and numerous other apparatus.

The use of this instrument for the measurement of capacities by alternating current is specially interesting in view of its being unaffected by wave-form, leakage, and change of frequency. There are many problems met by those engaged upon extra high-pressure supply which such an instrument might help to elucidate. If an alternator be coupled to some miles of underground cable we can, of course, calculate the capacity of the cables from the charging current and applied voltage. It is well known, however, that we generally get results which differ entirely from galvanometer and standard condenser measurements; we usually account for the difference as being due to the deviation of the pressure wave from a pure sine wave-form. If now, with the same alternator and cable, we alter the excitation and consequently the applied pressure on the cable, our results generally are still more inconsistent.

The fundamental properties of the shunt magnet connected to an alternating-current circuit, to which Dr. Sumpner called attention some time ago, and has now so ably embodied in the construction of measuring instruments of great practical value, should be appreciated by all electrical engineers who have to deal with alternate-current supply.

The instruments described by the authors of the present paper by eliminating errors due to hysteresis, wave-form, periodicity, etc., undoubtedly mark considerable progress towards the simplifying of alternate-current working, which has been in the past not altogether free from uncertainties.

It would appear that the equivalent of the principle underlying the use of the shunt magnet as described by the authors might even be capable of further application in the future to such a science as acoustics, for instance, where complicated wave-forms are dealt with.

Mr. Record. Mr. J. W. RECORD: The strong control and freedom from external influences renders these meters very reliable in their action, and the small phase error which does exist can be determined with accuracy and relied upon. It is a noteworthy fact that the calculated phase error of any particular meter is about identical with the measured value.

The instrument when used as a capacity meter has great advantages over other methods of measuring capacity, as the leakage current, if any,

through the condenser being in quadrature with the capacity current, has no effect on the indications of the pointer. Mr. Record.

When measuring small capacities it is advisable to tap the winding of a potential transformer so that high voltage can be applied to the capacity in series with the instrument moving coil, and a low voltage to the shunt magnet.

Dr. SUMPNER *in reply:* I have to thank several speakers for their generous appreciation of the instruments we have described, and am glad that the paper has led to such a good discussion. I was first a student of Professor Ayrton when he and Professor Perry were developing the earliest ammeters and voltmeters, and when they were the first to see and to utilise the advantages of using permanent magnets in commercial instruments. The remarks of Professor Ayrton, however flattering, are naturally pleasing to me. Mr. Evershed's speech contained many valuable observations. I shall only refer to those which seem to call for a reply. He criticised some of the explanations as incomplete, but this was largely intentional. We had no wish to repeat what is to be found in previous papers. The phasemeter was more fully dealt with, as it is now for the first time brought to the notice of the Institution. Its explanation on the ohmmeter principle, represented by Figs. 16 and 17, was the simplest Mr. Record and I could think of. I expected it to appeal to a maker of ohmmeters, but this seems not to be the case. The clearest theory of a phasemeter, and the ideal kind of scale for it, are no doubt matters of individual opinion. There is likewise no doubt that the ideal of the maker has to give way to the want of the buyer, whose need is a complex variable and includes both a real and an imaginary part. Dr. Sumpner.

Mr. Evershed has clearly grasped the importance of the E.M.F. induced in the moving-coil circuit, and his estimate of its value is correct It is one of the extraordinary facts about these instruments that the current due to this induced voltage is often greater than that due to the working current. The effect in question, though striking, is, after all, nothing new in wattmeters. An ordinary instrument taking 10 amperes at power factor 0·6 is traversed by an in-phase current of 6 amperes producing the true deflection, and also by a quadrature current of 8 amperes, which is supposed to have no effect at all. In the new instrument the conditions have to be, and can easily be, made such that the induced current does not affect the deflection. Dr. Drysdale's contention, that these instruments are merely forms of the familiar induction wattmeter, is erroneous, since the induction effect has to be made negligible before the wattmeter can be accurate. But it would take too long fully to discuss the important point raised by Mr. Evershed. It must suffice to say that this matter has formed the subject of a thorough investigation, the results of which were communicated to the Royal Society in the form of a paper * in October last. Those who honour me by reading that paper will find that it fully meets Mr. Evershed's queries, and that it "quite comes to grips with the subject of the wattmeter."

* "Alternate-Current Measurement," *Proceedings of the Royal Society*, vol. 80, p. 310.

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Professor Wilson pointed out the two ways in which the double quadrature principle can be applied to wattmeters, and showed that the deflection is independent of frequency and wave-form in only one of these cases. He incidentally refers to the electrostatic form of wattmeter, which is perhaps the only instrument which can be used for the *direct* measurement of power when supplied at very high potentials. Certain obstacles must be overcome before such instruments can be made both safe and accurate, and I know that Professor Wilson has studied and overcome these difficulties. I regret that he did not allude to the method he adopts, since it is of great interest.

Mr. Edgcumbe considers that the quadrature transformer is not free from magnetic disturbances, but he has probably overlooked the fact that only the secondary coil need be shielded. A stray flux passing simply through the primary does not affect the deflection at all. The secondary coil is absolutely shielded by the iron because it is placed in the air-gap, and is magnetically short-circuited so far as stray fields are concerned. He is more to the point when he says that the troubles of the iron-cored electromagnet have been removed from the instrument only to reappear in the transformer. The answer to this is that iron may be used for two purposes: to increase the sensitiveness or to shield the coils from stray fields. It is used for both purposes in the shunt electromagnet without giving rise to error, but in the quadrature transformer it is merely used for shielding, because the instrument is already highly sensitive. The result is that the air-gap can be so increased that the troubles of the series magnet disappear. The iron of the transformer only slightly increases the sensitiveness of the instrument. The result of a long and troublesome investigation on these transformers has been to show that it is a mistake to use the iron so as to increase the flux much above what it would be if the iron were removed. For this reason the form of wattmeter shown by Dr. Drysdale is of special interest to me. Dr. Drysdale states that he still prefers the series form of electromagnet. On this point we must agree to differ. The wattmeter he shows is certainly very simple to construct. I notice that he has designed the electromagnet like the quadrature transformer, and has placed the magnetising coil in a similar position. This form of magnet I pointed out in my previous paper as the best form to adopt, but my tests have shown that if the air-gap is large enough to reduce sufficiently the hysteresis error there is not much gain in sensitiveness due to the presence of the iron.

Mr. Edgcumbe objects to our way of rating wattmeters, but if the rating he suggests were adopted the wattmeter would either deflect off the scale for full-load current whenever the power factor exceeded 0·5, or else the instrument would be rated for a current for which it would not be commercially used.

Mr. Edgcumbe thinks we have overlooked the virtues of the dynamometer wattmeter. The new instrument is itself of the dynamometer pattern, because perfectly definite paths are provided for the magnetising and moving-coil currents. The ordinary dynamometer instrument,

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however good it may be for alternate currents, is equally good for direct currents. Why, then, is it never used for Wheatstone bridges, potentiometers, and induction tests? How is it that the Siemens dynamometer, which at one time was employed mainly on direct-current circuits, is now hardly ever used except with alternate currents? Of course, it is because there are other direct-current instruments much more sensitive and satisfactory even than those of the dynamometer class. This investigation really started with the definite and declared object of finding, if possible, instruments for alternate-current circuits having the desirable properties of those of the permanent-magnet moving-coil type. I consider that this object is now attainable with the aid of the shunt excited electromagnet.

The dynamometer instrument is at its best as a fixed standard of the Kelvin balance type, available alike for direct and alternate currents. It is by no means ideal as a portable working standard. It is true that most good alternate-current instruments can be checked on direct current. But such checking is usually done with the aid of good portable permanent-magnet instruments, and when similar instruments are available, as I believe is now the case, for alternate-current testing, the need for direct-current checking disappears. The advantage of direct-current verification is not due to the fact that the primary electrical standards are all steady current ones. It merely arises from the accidental circumstance that hitherto the most convenient and reliable portable standards have been permanent magnet instruments only available for direct-current working. It is no more a disadvantage of these new instruments that they can only be used with alternate currents than it is a disadvantage of permanent-magnet instruments that they can only be used with direct currents.

Professor Kapp's remarks, I am gratified to note, were mainly commendatory. As regards the question of wattmeters on unbalanced loads, he correctly supposes that I was referring to the case in which a single wattmeter is expected to measure the total power of an unbalanced multiphase circuit. The multiphase instruments he alludes to are not single instruments, but two or more instruments put into one case, and arranged to operate on a single moving system. Such instruments, like the more complicated commercial forms of phase-meter, are only correct on one assumption which can never be quite true in practice. The multiple instrument really consists of two or more complete instruments, each of which, when properly connected to the circuit will act by itself, and will have its own scale. The assumption referred to is that the true scale markings are in exactly the same position for each scale. Many of the best firms claim, as a sign of their care in manufacture, that each instrument they make is independently calibrated. This is not only a sign of careful manufacture, it is also a confession that even with the best firms it is not possible to construct instruments to work exactly to a predetermined scale. But this power is exactly what is assumed by a firm issuing a multiple instrument. Until such perfect construction is possible, multiple wattmeters and phasemeters cannot be quite correct on unbalanced 3-phase loads.

Dr. Sumpner.

Dr. Drysdale regards the new instrument as an "old friend," an induction wattmeter spoilt by additional complexity. I totally dissent from such a view. At best his theory amounts to using the new quadrature principle to give a quite novel aspect to the action of an old instrument, and to add one more to the various conflicting theories of its working. But his explanation is almost wholly assumption, and would involve as a consequence that induction ammeters and voltmeters could not work at all. The eddy-current disc and the series magnet do not fulfil the conditions necessary for a quadrature transformer. The reactive influence of the eddy currents on the magnet is wholly ignored, and also the self-induction of the current circuits. Nothing is said of the eddy currents due to the shunt magnet. It would be just as logical to assume that the disc forms the secondary of the shunt magnet winding, the eddy currents being in phase with the voltage and acted on by the series magnet flux in phase with the line current. This view would make the induction instrument appear like another "old friend"—the dynamometer wattmeter. But neither of these views is correct. They are each the result of assumptions which remind one of the definition of faith once given by a schoolboy—the belief in that which we *know* to be untrue. In the new instrument each part has its definite function to perform, and the precision with which it acts can be accurately verified by measurements which are quite independent of the normal action of the instrument. The mathematical theory of the eddy-current instrument has been as yet far too complex for solution, whereas the theory of the new instruments has been completely worked out.

Mr. Irwin's resistance method of compensation is one of the two methods referred to in the paper as having been investigated and found satisfactory. The other method, involving an extra winding on the electromagnet with the ends of this winding connected through a condenser, is described * in one of the patents taken out in connection with these instruments.

Another method dependent on a principle which I pointed out in a paper on "Self Induction," read here in 1887, consists of simply shunting a condenser to the non-inductive resistance placed in the moving-coil circuit. Either of these condenser methods can be used to neutralise the self-induction error for all commercial frequencies, while by the resistance method the magnet error can be compensated, also for all frequencies. Each method can be used for over-compensation, and for completely neutralising the instrument error for the working frequency of the circuit.

The resistance method is very simple and convenient, and is applicable when the line current is at low potential and not too great in magnitude, as, for instance, when the instrument currents are supplied through current transformers. I am much indebted to Mr. Irwin for recalling my attention to this method, for although I had noticed it

* Patent 2416 of 1907. For experimental verification see *Proceedings of the Royal Society*, vol. 80, pp. 344–350.

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before, I had not fully realised its possibilities. In many cases a condenser method is preferable, and one of these has the great advantage that it can be used not only for the quadrature wattmeter, but also for neutralising the errors due to the variable properties of the secondary circuit of ordinary current transformers, which errors in practice are usually more serious than those intrinsic to the actual wattmeter used. The error of the new instrument is small and obeys a precise law. This makes exact compensation easy. The resulting advantages are clear, for the instrument can be made smaller and more sensitive without loss of accuracy.

I am glad to have the data furnished by Dr. Garrard and Mr. Phillips in reference to the torque for 90° deflection for certain instruments, but it must not be supposed that 1·2 gramme-centimetres is the maximum attainable with those of the type now described. In one of those I possess the torque is over 3 gramme-centimetres, and this is by no means the limit, especially for "extra large" instruments. Indeed, now that certain restrictions on the design are removed by the use of compensating devices, it is possible to increase the torque to any reasonable extent.

Mr. Russell's remarks raise some subtle questions about vector diagrams and wave-forms. It would take too long to discuss them. They are dealt with in the Royal Society paper already referred to. As regards the distortion of the field due to eddy currents, if it is borne in mind that the iron is well laminated in planes perpendicular to the working conductors, it will be seen that no such effect can become appreciable. Mr. Russell alludes to the instrument indicated in Fig. 22, and suggests an experiment which would at present be too severe a test for a single-phase meter of any known make. In the corresponding 3-phase case it would be impossible to adjust the balance of the load in the sense needed to justify the assumptions always made in reference to phasemeters. As already pointed out, the phasemeter really measures a ratio, and can only be calibrated for power factor if certain assumptions are fulfilled. A phasemeter for 3-phase circuits, if really independent of the balance of the load currents, would indicate correctly if one of these load currents were made zero by breaking the corresponding main. No existing phasemeter would stand such a test. The present paper was written in October last, and since then the instrument illustrated in Fig. 22 has been greatly improved by introducing fine wire voltage-winding for the stator. Small condensers may thus be used for supplying current to some of the coils of the multiphase electromagnet, and, with the help of the other well-known means available, may be used to make more regular the rotating magnetic field. The single-phase instrument can be made quite satisfactory for ordinary commercial circuits, though not such as to be quite correct under the extraordinary conditions Mr. Russell suggests.

Mr. Phillips makes some natural criticisms in reference to the wattmeter, but they are chiefly based on misconception. The damping arrangement in a few early cases did give rise to the trouble he

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mentions, but the design has since been modified and made quite satisfactory. There is, moreover, no need for the vane to be at the end of the pointer. In two of the instruments actually shown to the meeting, the vane and the damping box are on the same side of the axis as the moving coil. Mr. Phillips regrets the need and expense of the quadrature transformer, but he forgets that the current coil of the ordinary wattmeter is not needed, and also that the heavy current leads need not be taken up to the instrument. For heavy current work it is clearly an advantage to place the quadrature transformer, like the shunt of an ammeter, where the main leads naturally lie. For small current work this is not important, but the transformer can be placed in the instrument case, though this has not yet been done. The criticism made of the arrangements shown in Fig. 8 is completely met by those of the adjoining Fig. 7 [which is more fully explained in Appendix II.]. Mr. Phillips has quite misunderstood the remarks about frequency. With every instrument there is some limiting voltage which should not be exceeded, and it was necessary to point out in reference to the new instruments that this limit depends upon the frequency of the current. An instrument normally excited at the rated voltage for circuits of 50 ∿ may be used with this voltage for currents of any *higher* frequency, but not for currents of frequencies *lower* than 25 ∿. This does not imply any limit in frequency range, except that for every instrument there must be a lower limit due to the saturation of the iron core. Instruments can be wound for frequencies lower than 25 ∿, and there is no practical *upper* limit to the frequency with which they may be used.

With reference to Dr. Morris's remarks, I ultimately gave up the simple theory of the phasemeter dependent on the assumption of a true rotating field because this assumption was not found accurate enough. The theory itself is correct, but in actual motors and instruments the rotating magnetic field is not precisely regular in the mathematical sense assumed. With regard to the behaviour with irregular wave-form, phasemeters for 3-phase circuits are quite correct on all wave-forms if they are properly calibrated and if the three-line currents are equal. They are also right on all frequencies.

Mr. Coales referred to the action of transformers in conjunction with wattmeters, and mentioned a test in which apparently he attempted to use an ordinary current transformer as one of the quadrature type. Such a test naturally failed because the two classes of transformer are radically different. The ratio of the ampere turns of the secondary coil to those of the primary must be made in one case as near unity as possible, and in the other case as near zero as possible. In one case the magnetic circuit must be closed, but core losses are unimportant. In the other case the magnetic circuit must be open, and even a small core loss is serious. It is unfortunate that watt-meters generally get the blame for the considerable errors which really arise through the current transformers. In practice it is often the case that it does not much matter whether the wattmeter used is good or

bad, since the current transformer introduces errors entirely throwing into the shade any error which may be due to the wattmeter itself. Dr. Sumpner.

Mr. Kemp referred to the need of edgewise instruments in cases where switchboard space is limited. The new instruments can without difficulty be adapted to the edgewise shape of case, and also to the integrating form of meter, but the mechanical details have not yet been worked out. Ordinary current transformers can be used with the new instruments to supply current to the quadrature transformer, but this latter must be regarded as the current coil of the wattmeter, and as an essential part of it.

In reply to Mr. Taylor, the result of four years' experience has been such that we cannot recommend the use of series electromagnets for wattmeters, but in regard to ammeters and phasemeters there is no disadvantage in the use of such current-controlled electromagnets. The shunt, or voltage controlled, magnet is specially fitted for voltmeters and wattmeters since the field can be made very strong without causing error. In consequence the new instruments are more robust than others having the same accuracy.

Mr. Brew's remarks about the commercial importance of accurate measurements on alternate-current circuits are very much to the point, and also those in reference to the numerous installations in which the current transformers and wattmeters are supplied by different contractors. Mr. Brew points out that switchboard instruments are of two kinds. Those of the first class, such as voltmeters and wattmeters, are needed to measure, and must be accurate and reliable. Those of the second class, such as ammeters and phasemeters, are chiefly wanted to indicate the running condition of the plant. The phasemeter is an instrument which can be made very accurate, but its main use at present to the station engineer is to show him at a glance whether an alternating-current machine is working efficiently and steadily. This function the phasemeter performs admirably, the more so as its indications are independent of temporary fluctuations in the load (as distinct from phase swinging). It is the only instrument at present available for this purpose, but its usefulness does not yet seem fully realised.

After the discussion there was a demonstration illustrating the use of the instruments. At Birmingham there was also a demonstration of the use of the oscillograph. This included—The effect of the paralleling of alternators; stator and rotor current waves in an induction motor; voltage and current waves of the primary and secondary windings of a transformer; hunting effects in a rotary converter, &c. Various methods of measuring slip were demonstrated, and some interesting experiments with frequency indicators were shown.

At both meetings at which the paper was read a hearty vote of thanks was accorded to the authors.

Proceedings of the Four Hundred and Seventy-fourth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 2, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on March 19th were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

T. P. E. Butt. | A. P. Rutherford.
George E. Wright.

From the class of Associates to that of Associate Members :—

P. P. Shilston. | F. W. Thompson.

From the class of Students to that of Associate Members :—

E. R. Alexander. | W. H. Mayston.
Claude R. Barry. | Philip H. Morgan.
B. G. Drummond. | Lewis W. Phillips.
J. W. Fidoe. | Wilfrid S. Taylor.
W. B. Marr. | Robert W. Willis.

Messrs. L. T. Healy and C. K. Falkenstein were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Lalit Chandra Bose. | Frank Arthur King.
Arthur Robert Gundry. | Gerald Lloyd-Jones.
Harold Firth Haworth, Ph.D. | William Tolmé Maccall.

As Associates.

Frederick Berry. | Albert Enrico Kiralfy.

As Students.

John Russell Abbott.
Andrew Niven Aikman.
Alexander Jonathan Airston.
Charles Gordon Barker.
Robert Frank Blackmore.
Sidney Haines Bridcut.
Henry Brittan.

Donations to the *Library* were announced as having been received since the last meeting from The Berry Transformer Company, H. Ineselhorst, H. R. Kempe, Messrs. Lloyd Wise & Co., T. Mather, L. H. Walter, Messrs. J. Wiley & Son; to the *Building Fund* from Joshua Shaw; and to the *Benevolent Fund* from J. R. P. Lunn, to whom the thanks of the meeting were duly accorded.

The following paper was read and discussed:—

HIGH-SPEED ELECTRICAL MACHINERY.

By GERALD STONEY, B.Eng., Member, and
A. H. LAW, B.Eng., Associate.

(*Paper received February 6, read in London on April 2, and at Newcastle on April 6, 1908.*)

The introduction of electrical machinery some twenty-five years ago familiarised engineers with comparatively high speeds of rotation, the small dynamos of that date generally running at from 1,000 to 1,500 revolutions per minute, necessitating as a rule a belt drive to raise the speed from that of the engine to that of the dynamo.

The first high-speed dynamo made for direct coupling to a steam turbine was, we believe, designed and constructed in 1884 by the Hon. C. A. Parsons (Patent 14723/84). The chief features of interest as described in the patent are those which relate to the provisions to meet the centrifugal forces, the spiral end windings of the drum armature, and the construction of the commutator segments in short lengths dovetailed into steel rings with asbestos insulation.

Fig. 1 shows the construction of this dynamo; the armature is 2⅜ in. in external diameter, and the core, built of very thin iron plate, is 2¼ in. diameter and 8 in. long. There are 50 conductors, and at 18,000 revs. per minute (the normal speed) the output was 75 amperes at 100 volts, or 10 E.H.P.

The surface speed of about 206 ft. per second of the armature was a great advance on previous practice, but still more unusual was the speed of alternation of magnetism in the iron of the armature, which in the absence of any but external cooling made it necessary to reduce the losses in the armature to a minimum.

Internal cooling by means of a flow of oil through a hole in the armature shaft was tried, but was in later plants discarded as relatively ineffective.

Thus at a single step the ordinary speed of dynamos was increased from ten to fifteen times, which ratio it is of interest to note still fairly represents the difference in speed between reciprocating engine and steam turbine practice for given sizes of electrical generating plants. Although at this early date in the history of the steam turbine it was naturally the turbine that created most interest, it can safely be said that without the high-speed dynamo—in many ways quite as difficult or even a more difficult problem—there would have been no steam turbine as we know it to-day. It will be easily understood that an entirely new set of mechanical problems had to be faced when it is

mentioned that since this early armature was run in a steam turbine, a surface speed of about 200 ft. per second, the commutator was about 12,000 times greater in its working capacity, weight for a centrifugal force of about 5¼ tons.

In this early armature the spindle was of high carbon steel to give the greatest possible strength, the diameter of the core being 4 in. and the bearings 3 in. diameter by 5¼ in. long. The core is mounted on a cast-iron spider with notched driving discs or rod ties at each end, and consists of a wound drum-winding with barrel ends, the whole being held together by binding wire to withstand the centrifugal force. The commutator is made up of sections held by dovetailed rings with asbestos insulation. It will be seen that from the first the necessity of long cores of small diameter was recognised, and it is remarkable how close the magnetic densities, ampere-turns per inch diameter of core and other electrical quantities agree with what we would now adopt if we were called upon to make a similar dynamo, and this is all the more remarkable as the theory of the dynamo was very imperfectly understood twenty-four years ago, little being known about magnetic densities and still less about hysteresis and eddy currents. The iron available in those days for the core plates had about four times the hysteresis loss of modern armature iron, but this was probably to some extent counterbalanced by the very high periodicities which made the hysteresis losses small in comparison to the eddy-current losses.

It is interesting to note that with 80 lbs. per square inch pressure at the stop valve the steam consumption of this first steam turbine, which was non-condensing, was 120 lbs. per kilowatt hour.

These armatures gradually increased in size until in 1889 the type had the size of 60 k.w. at 6,000 revs. per minute, the cores being 7 in. diameter and 18 in. long, the output being 600 amperes at 100 volts.

These early types of dynamos were all bipolar with shunt wound horse-shoe magnets. The number of commutator segments were usually 12 for 50 or 65 volts, and 18 for 80 to 100 volts, and in all but the smallest sizes there was only one complete armature turn per segment.

In these plants the speeding was [illegible]

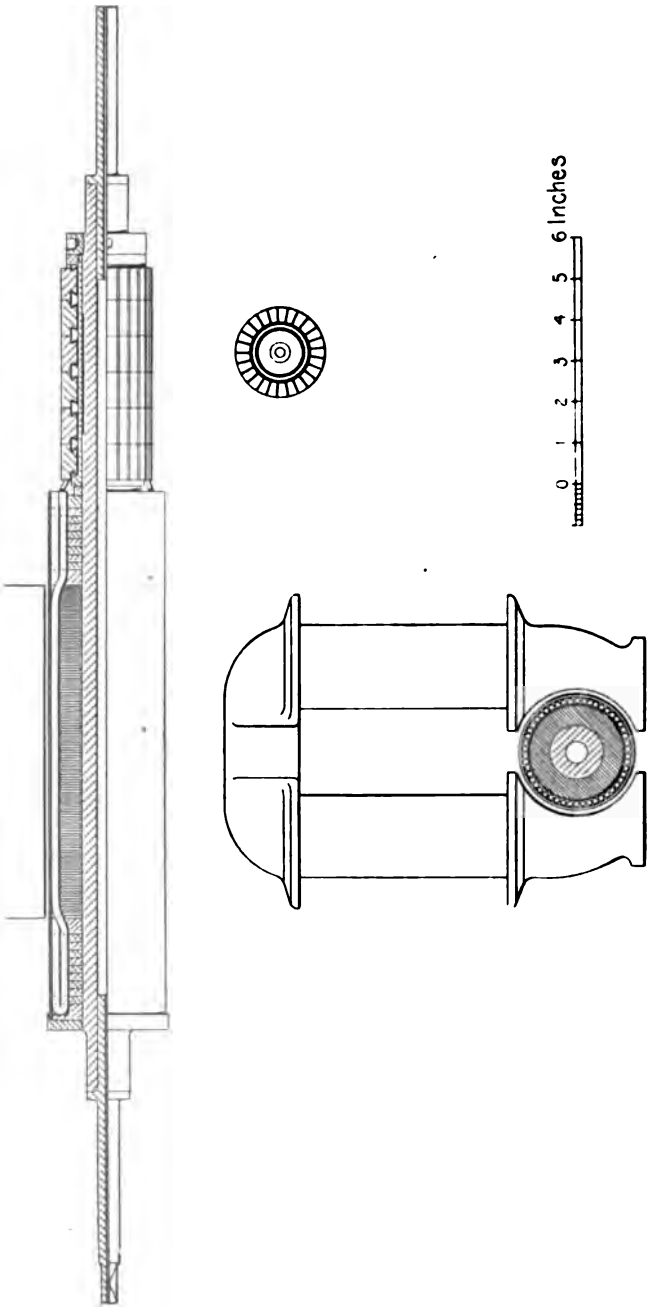


FIG. 1.—Old Type Continuous-current Armature.

insulated discs at each end of the core, each connected to opposite conductors, an arrangement identical electrically with the ordinary drum-winding, but although it worked very well the cost and difficulty of manufacture were found to be excessive, and it was decided to adopt a Gramme armature. Besides this, it was early seen that for a given voltage a certain number of commutator segments were necessary, and that the sparking to a large degree depended on the ampere-turns in the armature, and since the Gramme armature had twice as many segments as the drum for the same number of conductors it appeared that the result should be better.

Several turbo-dynamos were made with armatures of this type, the most noticeable being some of 400 k.w. for 500 volts running at 2,200

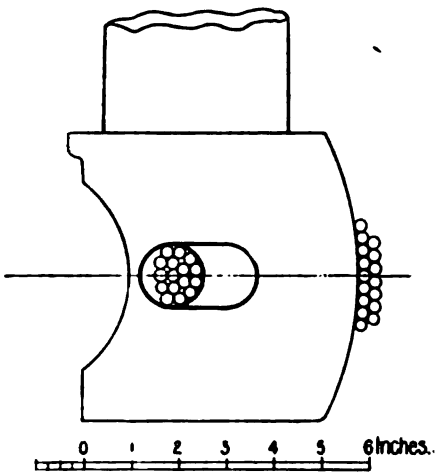


FIG. 2.—Compensating Winding made 1885. Copy of Original Drawing.

revs. per minute, and some of 150 k.w. for the same voltage at 3,000 revs. per minute. The former of these sets had two armatures to each machine, these armatures being both mounted on the same spindle with their commutators at opposite ends, and both these and the 150-k.w. plants are doing good work to-day.

At this time also was introduced the construction of commutator with steel rings shrunk on over mica holding the segments in place against the centrifugal force, a construction which has been universally adopted by all makers of high-speed dynamos. Also, in some cases, fan blades were fitted to these commutator rings for the purpose of cooling both the armature and also the commutator.

The chief defects of these armatures were that sparking was not reduced, owing to the large self-induction of a Gramme winding, and that the heating was excessive both on account of the difficulties of

effective ventilation and also through the heating of the spindle due to its revolving in the stationary internal field of the armature.

For these and other reasons on the recovery of the patents in 1894 the drum armature was reverted to with considerable improvements in detail, ventilating ducts being provided along the cores to give internal cooling, and the conductors being much more efficiently laminated. And here it may be said that in all these high-speed armatures the cores are smooth, or nearly so, and the windings extensively subdivided to prevent eddy currents. Slotted cores for high-speed armatures have been used with some success, but on account of the much higher self-induction of the windings it is impossible to obtain as good results as with the smooth core type. Slotted core armatures have been built by Messrs. C. A. Parsons & Co. on several occasions, but results were never obtained which could in any way compare with those given by smooth, or nearly smooth, cores.

In some of the most recently built armatures of large size the conductors have been laid in slight grooves in the core. These grooves provide a means of preventing the conductors from moving, and the iron between the conductors reduces the reluctance of the air-gap to some extent. The conductors are held to the core by binding wire made of steel piano wire, a material which long experience has shown to combine the qualities of reliability and high tensile strength, which render it immensely superior to such material as phosphor bronze. Its magnetic properties are its one defect, but careful tests have shown that these are relatively of minor importance.

A series of experiments made about 1887 showed that in small turbo-dynamos of 12 to 16 k.w., running at speeds of from 8,000 to 9,000 revs. per minute, giving periodicities as high as 130 to 150, the saving in power obtained by using phosphor bronze instead of steel wire amounted to only about 2 per cent., and a further series of experiments conducted in 1904 on two 150-k.w. armatures at 3,600 revs. per minute showed a saving in power of less than 0·30 per cent. by using phosphor bronze wire, and it is still less in larger armatures.

Against this saving must be set the fact that phosphor bronze has much lower tensile strength, and therefore a larger quantity is required. Also bronze wire is liable to have occasional soft spots of weaker material, which is a fatal defect, and it is a matter of experience that steel binding wire, when properly applied, is extremely reliable. Further, the surface construction enables the insulation of the conductors to be carried out in a very complete manner, so that there is no danger of insulation being cut locally by sharp corners or projections from the core plates.

In all these earlier dynamos the magnets were of the ordinary type, generally horse-shoe; but even when the size was limited to 200 k.w. at 3,000 revs. per minute, although the commutation was good when the brushes were properly set for the load, heavy sparking was experienced on large variations of load, such as is met with in the case of traction plants.

The first method of meeting the difficulty was to shift the brushes automatically according to the load, this being effected (see Parsons and Stoney's patent 9203/00) by moving the brush rocker by a piston controlled by a spring and actuated by the steam pressure at the inlet to the turbine. The angular movement required by the brush rocker is approximately proportional to the load, and the pressure at the inlet to a turbine is also proportional to the load, so that it is easy to arrange for the brushes to be shifted the right amount. This arrangement, however, had the defect that it was not rapid enough to meet sudden and large changes of load, and under such circumstances some sparking occurred during the interval of lag.

In the year 1891 Professor Forbes took out a patent for a special winding to prevent distortion of the magnetic field in homopolar dynamos. The primary object of this patent is stated to be the correction of distortion in homopolar machines, but the patent is also extended to other classes of dynamo electric machinery.

In Professor Forbes' arrangement the current passed along one pole in a direction opposite to the direction of the current in the armature under that pole, and back along the other pole. In the early Parsons arrangement of 1885 what corresponds to a ring winding was used, the active wires being embedded in the pole-face, while the return was made at the back of the poles, as shown in Fig. 2.

The Forbes specification definitely states that the number of wires on the polar faces is half the number on adjacent parts of the armature, and this gives a number of ampere-turns in the compensating winding equal to the ampere-turns of the armature, and the want of sufficient ampere-turns was the reason why the arrangement did not yield the remarkable results obtained in later years.

In 1903, after a series of experiments, Messrs. C. A. Parsons & Co. constructed a 300-k.w. 2-pole compensated dynamo working at 3,000 revs. per minute at a voltage of 500, in which the ratio of compensating ampere-turns to armature ampere-turns was as high as 2·4. The armature dimensions (with the exception of the commutator, which was of course larger) were similar to the standard 200-k.w. plant of that date, and at once remarkable results were obtained, since it could be loaded up to 800 k.w., and when that, and even greater loads, were thrown on and off with a circuit breaker, there was no need to alter the position of the brushes nor was there any excessive sparking.

This type of compensating winding is now being exclusively used by the above firm, with modifications of detail only, on all their continuous-current turbo-generators. As this compensating winding, which generally is chiefly concentrated on the pole-pieces, is made with 2 to 2½ times the number of ampere-turns that are on the armature, there is a very large excess sufficient both to neutralise the distorting effect of the armature windings on the field and at the same time to provide a commutating field for reversing, without sparking, the current in the coil undergoing commutation. Owing to the width of this field the brushes need not be so accurately set, and there is considerable range of sparkless commutation at all loads.

Since this method of compensating has no iron commutating pole it has the advantage that there is no self-induction to cause time lag at sudden changes of load ; as the field in the gap between the poles is entirely in air it instantly responds to changes of current in the compensating winding, and thus the sparking often seen when there is a sudden change of load with commutating poles is avoided and the risk of a flash-over largely reduced. Also, since there is no iron to become saturated, the commutating field is always strictly proportional to the load, and thus the trouble due to saturation causing sparking at some

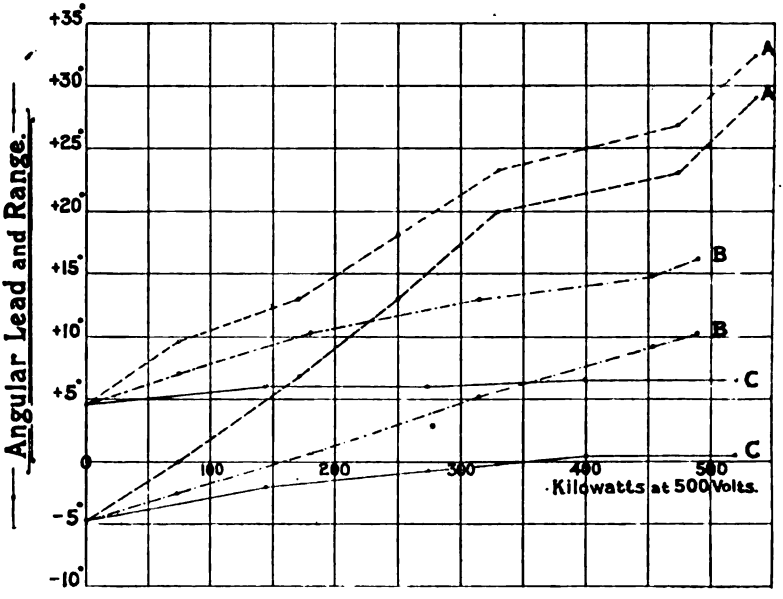


FIG. 3.—500-k.w. Turbo-Generator. Brush Ranges.

loads and not at others is avoided. This advantage is felt still more when the dynamo is required to give varying voltages and to commutate well at any of them without any adjustment of the compensating winding by diverters or otherwise.

The effect of this compensation is clearly shown in the diagrams in Fig. 3. These curves are commutation curves taken off exactly similar machines with varying amounts of compensating winding. Each pair of curves represents the limits of brush movement expressed in degrees, within which the commutation was sparkless.

The two curves marked A A were taken on a machine (500-k w.) with the compensating winding cut entirely out of action. It will be seen that only about 120 k.w. could be carried without having to move the brushes, while at about 300 k.w. the limits became very narrow,

and beyond this no satisfactory commutation position could be found. Curves B B show the limits with a ratio of compensation (that is, ampere-turns on field to ampere-turns on armature) of 1·6. In this case 300 k.w. could be carried without having to move the brushes, and though the limits narrowed slightly considerable overloads could be easily carried without sparking if the brushes were slightly rocked forward. It may be of interest to state that this machine was one of the first to be fitted with compensating winding, and as a slight brush movement was required up to full load it was also fitted with automatic brush-gear.

Curves C C show a sister machine to the above-mentioned with compensating of about 2·2 times the armature ampere-turns, and here it will be seen that there is no brush movement, and that were the machine used as a motor it would be quite reversible so far as commutation is concerned, and that it can carry safely heavy over-loads.

The advantages of a compensating winding will easily be seen to be much more than those due to fixed brushes and better commutation, since it has enabled not only the number of segments for any given voltage to be reduced but also the ampere-turns on a given diameter of armature to be increased. This enables a larger output to be obtained for a given speed, or what is the same thing, a higher speed to be used for a given output. Before compensating was adopted a 500-k.w. at 1,800 revs. per minute was the extreme limit of size for that speed, and the machine would not carry more than 10 per cent. overload, now we have made a 500-k.w. running at 3,000 revs. per minute, or a 750-k.w. running at 1,800 revs. per minute, carrying 25 or 30 per cent. overload without sparking, and 50 per cent. for a short time without injurious sparking. This has enabled not only the cost of the turbine to be largely reduced, but also the steam consumption to be lowered by some 10 per cent.

It may here be mentioned that no difficulty has been experienced in running these compensated dynamos in parallel with one another or with other types, although in all cases they are self-exciting, no separate exciter being used.

Figs. 4 and 5 show a 1,000-k.w. dynamo for 500 volts running at 1,200 revs. per minute, two of these being coupled to a 2,000-k.w. turbine. These dynamos are for 500 to 600 volts, and carry an overload of 25 per cent. for two hours without sparking or undue heating. They are 4-pole, the armature core being 36 in. in diameter and 23 in. long, with 192 conductors. The commutators have 96 segments and are 18 in. in diameter with an effective length of 24 in.

Fig. 6 is a 750-k.w. at 1,800 revs. per minute for 480 to 560 volts. It is a 2-pole, the core being 27 in. in diameter and 25½ in. long, the commutator having 42 segments, the diameter being 14 in. and the effective length 33 in., the number of conductors being 84. This machine has very good commutation, an overload of 33 per cent. or 1,000 k.w. being able to be suddenly thrown on or off without any sparking whatever being visible at the brushes.

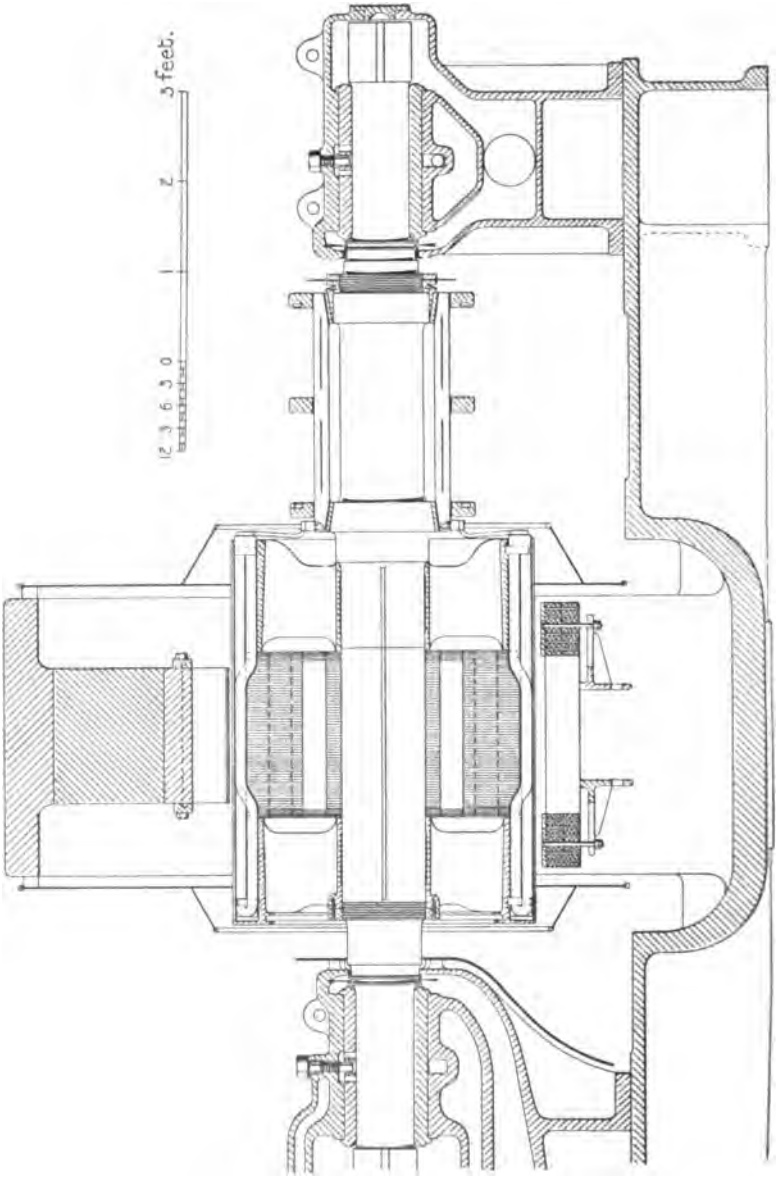


FIG. 4.—1,000 k.w. Turbo-Generator, 500 volts, 1,200 revs. Longitudinal Section through Dynamo.

We have found brass-wire brushes running on a grooved commutator to give the best results. The grooving has the advantage of increasing the surface of contact, and of allowing the brush better to follow the irregularities of the commutator.

The formation of commutator before referred to, and at present used by all manufacturers of high-speed continuous-current dynamos, was

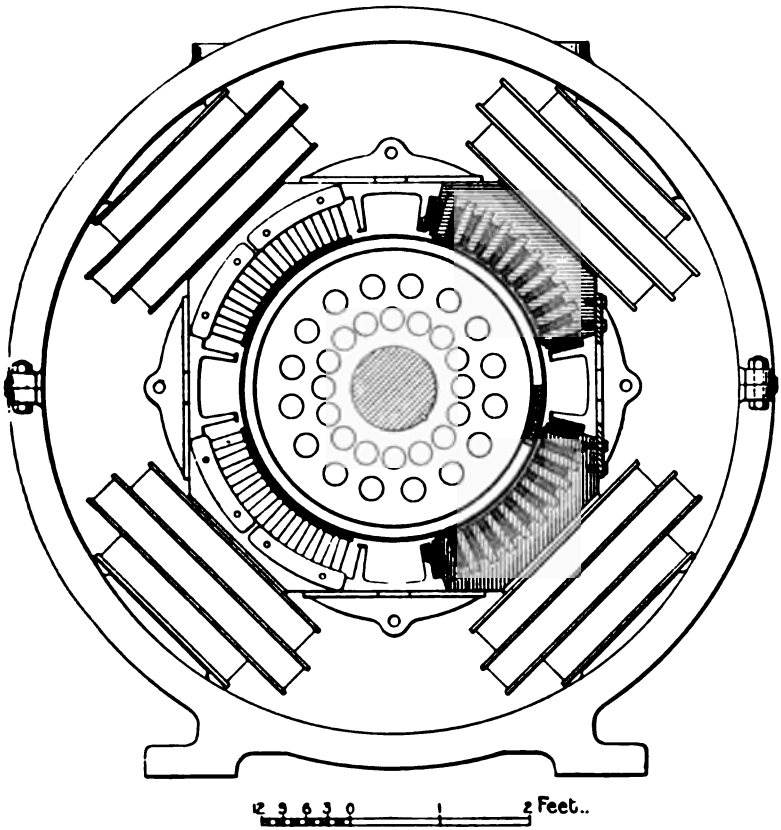


FIG. 5.—1,000-k.w. Turbo-Generator, 500 volts, 1,200 revs. Cross Section.

first designed in 1890 by Mr. Parsons, and has since been used with very few modifications, and a brief description of the commutator and the method of building it up may be of interest.

The bars are held in place against centrifugal force by massive steel rings shrunk on over mica bushes, and the commutator as a whole is supported on cones at each end. One of these cones is so arranged that it has a small amount of liberty to slide along the shaft

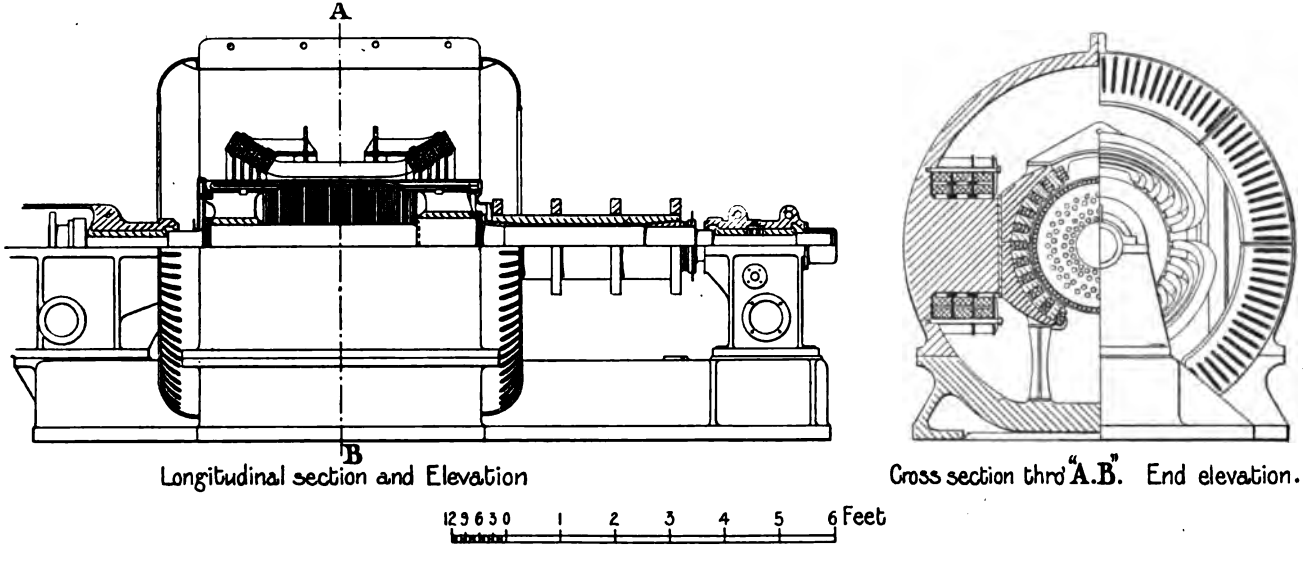


FIG. 6.—750-k.w. Turbo-Generator, 480 to 560 volts, 1,800 revs.

longitudinally, and thus allow for the expansion and contraction of the copper.

In building the commutator, the bars with mica insulating strips attached are first assembled and held in place by massive clamps, or by one or two layers of steel binding wire put on temporarily. The mica for one of the rings is then built up by slipping pieces of leaf mica under large rubber bands, and when a sufficient thickness has been obtained the mica is tied in place with string and the rubber bands removed. A steel ring is then slipped on at a red heat, stops being arranged to make it take up its proper position. As it goes on it burns away the string and grips the mica so tightly that the latter can readily be turned and trimmed back close to the ring, and presents a smooth black surface like a solid mica sleeve. In a commutator with only one section there are two of these steel rings, one at each end, but in long commutators several are required to counteract the centrifugal force tending to bend the commutator bars.

The first turbo-alternators made were for the Newcastle and District Electric Lighting Company, Ltd., four 75-k.w. sets being installed in 1889 in their Forth Banks station. They generated single-phase current at 1,000 volts, and being 2-pole on a supply at 80 ∿ ran at 4,800 revs. per minute (see Fig. 7). They were of the revolving armature type, and had a smooth core 7¼ in. diameter by 30 in. long with a single shuttle winding held on by binding wire, the ends being brought to slip rings. External or surface ventilation was solely relied upon for the dissipation of heat. These early alternators ran quite satisfactorily for about fifteen years, when they were removed to make room for larger units.

A considerable number of turbo-alternators of 150 k.w. at 4,800 revolutions were made for the electric supply stations in Newcastle, Cambridge, Scarborough, and other places, having cores 8¼ in. diameter and 32 in. long. As it was seen, however, that in the larger alternators more surface for the dissipation of heat would have to be provided than that presented by the exterior of the armature alone, a square 4-in. spindle was employed with radial ducts and holes through the winding to pass air for cooling as shown in Fig. 8. Many of these machines which were made between 1891 and 1894 are still running and doing good work.

In 1894 the first of a series of 350-k.w. turbo-alternators was made for the Manchester Square Station of the Metropolitan Electric Supply Company. These supplied single-phase current at 1,000 volts, and had 4-pole revolving armatures running at 3,000 revs. per minute, giving 100 ∿. Their cores were 17¼ in. diameter by 57 in. long, and were provided with twelve 1¼ in. holes passing the whole length of the armature, air being drawn through by a fan though no radial cooling was provided. The first few were surface-wound, but owing chiefly to the eddy currents developed in the conductors, which were large and insufficiently laminated, there was considerable trouble from heating, and they were subsequently altered to a tunnel winding with

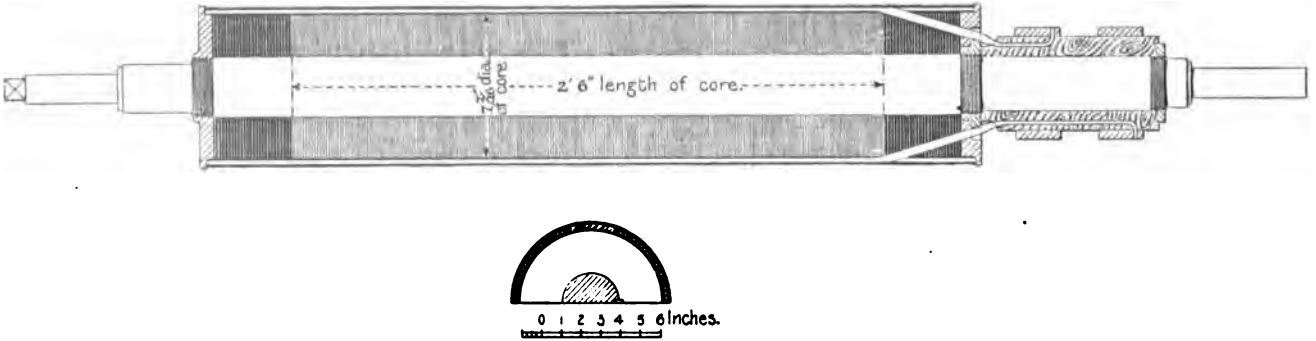


FIG. 7.—75-k.w. Single-phase Turbo-alternator Armature.

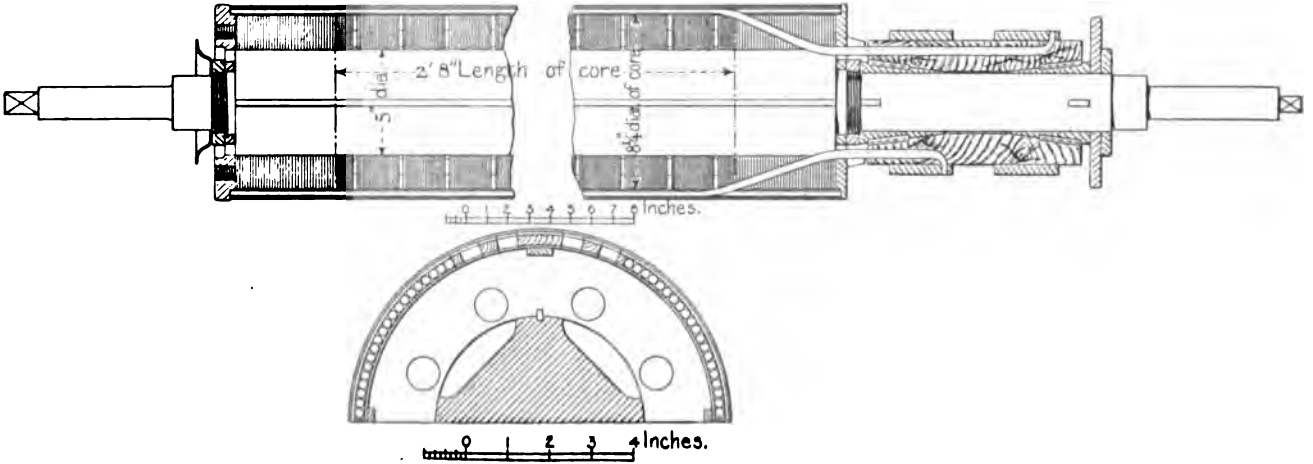


FIG. 8.—150-k.w. Single-phase Turbo-Alternator Armature. Showing Air-cooling Ducts.

sixty holes ¾ in. diameter, forty of which were filled each with one conductor, the remaining twenty holes being empty since the alternator was single-phase. We may mention that in Plate XV. of Professor Silvanus Thompson's "Dynamo Electric Machinery," 1896 edition, there is a section of these alternators. This type of alternator was very satisfactory for single-phase work, the largest made being of 1,000 k.w. for the city of Eberfeld in Germany. The armature core was 36 in. in diameter by 48 in. long, and the machine ran at 1,500 revolutions, giving 4,000 volts at 50 ∿.

Two- and three-phase alternators were also made on the same lines up to 500 k.w. at 500 volts, and even 2,000 volts, the most noticeable of this type being the two 1,500-k.w. 2-phase 2,000-volt plants, which were installed in 1904 at the Neepsend Station of the Sheffield Corporation, and have run ever since without giving any trouble.

The crossing of the windings at the ends, however, makes the problem of a revolving polyphase armature much more difficult, especially at high voltages, though, on the other hand, the iron loss, especially in 2-pole plants, is only about one-third of what it is with a revolving field. The real trouble came when it was attempted to make a 1,500-k.w. 40-∿ 4-pole 3-phase alternator, with a revolving armature running at 1,200 revs. per minute, and a voltage of 6,000. It was found impossible to insulate sufficiently the end windings and at the same time to get rid of the heat generated, and as a result the modern type of revolving field was adopted.

In revolving-field high-speed alternators of various constructions there is comparatively little difference in the design of the stationary or high-tension element. This follows low-speed practice fairly closely, though the external appearance is widely different owing to the few poles, small diameters, and greater length of the high-speed plant. It has, however, been found necessary to introduce a special system of brackets or clamping rings to hold the end windings against the enormous forces developed in case of a short or other serious disturbance on a system. In the case of several alternators running in parallel these forces may be so great that every precaution must be taken to prevent movement of the coils, and no make of turbo-alternators has been free from trouble from this cause, though in our recent designs the coils are so stayed as to be proof against the most severe short circuits, and the necessity of thus supporting the end windings as firmly as possible is now recognised by practically all makers of high-speed alternators.

Figs. 9 and 10 show a longitudinal and cross-section of the 4,000-k.w. 3-phase alternators at 6,000 volts installed at Carville power station. The stators are split along the horizontal diameter and so arranged that the top half can be lifted by breaking only four electrical joints. This construction has the advantage for plants of large size that the rotor can be lifted out direct, but it rather complicates the end windings. The plant illustrated is capable of carrying

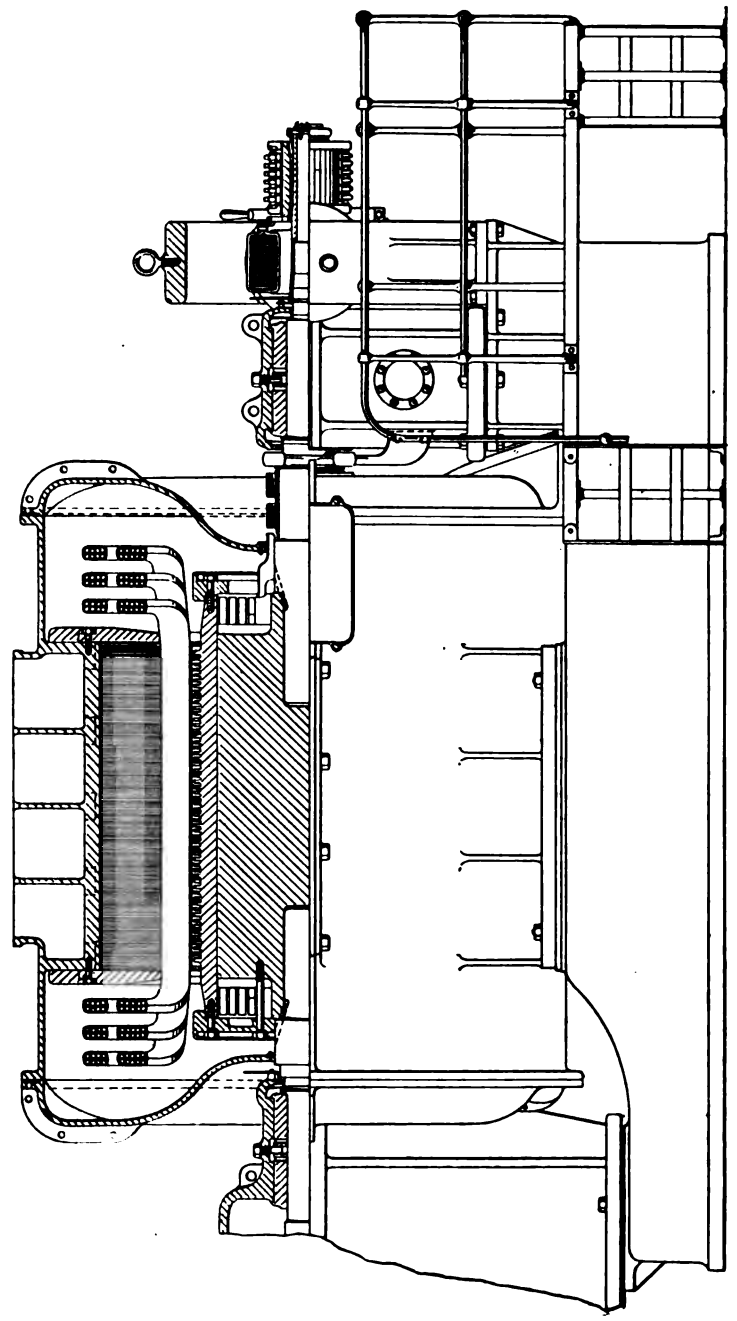


FIG. 9.—4,000-k.w. 3-phase Turbo-Alternator with Exciter, 6,000 volts.

6,000 k.w. for two hours, and on its official trial was loaded for half an hour up to 7,000 k.w.

There are under construction at the present time two 5,000-k.w. alternators for 6,000 volts at 750 revs. per minute of this type for the Sydney tramways. These plants are guaranteed to do 6,250 k.w. con-

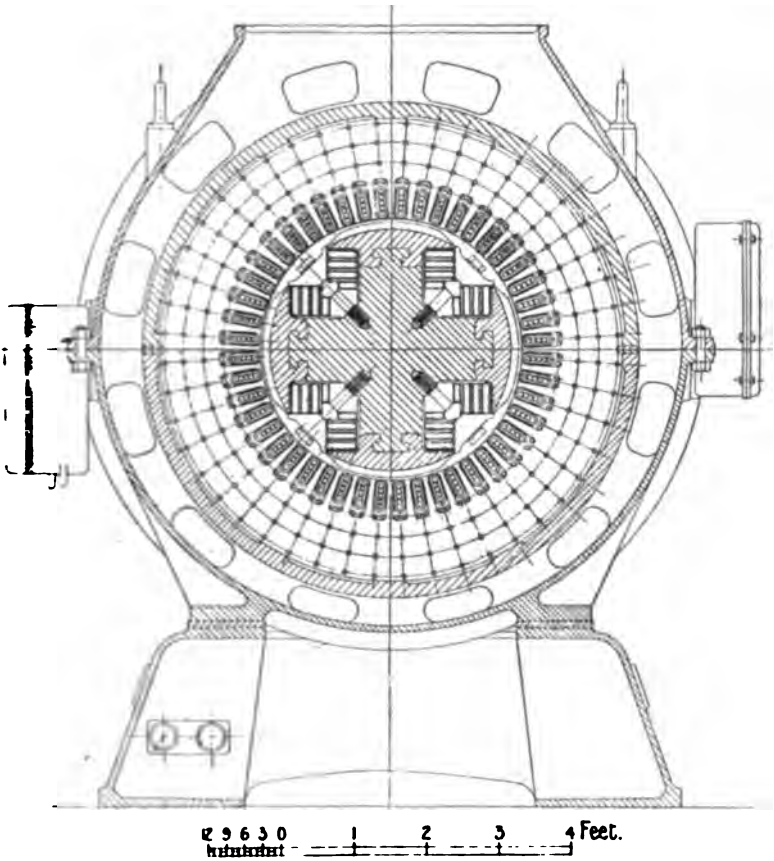


FIG. 10.—4,000-k.w. 3-phase Turbo-Alternator, 6,000 volts. Cross Section.

tinuously, 7 500 k.w. for two hours, and to have a temperature rise not exceeding 45° Fahr. when run continuously at full load.

It is, however, in the rotors of high-speed alternators that the greatest diversities of design are to be found. A great deal has been said as to the relative merits of salient pole as compared with cylindrical-type rotors, especially as regards the voltage regulation of the alternators, some designers advocating the former as strongly as others

support the latter, but it appears that a much more important question is whether one design shows marked advantages mechanically over the other. Any difference there may be in the two types as regards voltage regulation is certainly small, and can easily be compensated for at small expense by other features in the design.

A large number of alternators of the salient-pole type are in successful operation, and though in the early days there were mechanical troubles caused by the coils moving and chafing the insulation, modern methods of construction have quite done away with this source of trouble.

The question of ventilation is of very great importance in modern high-speed plant owing to the compact nature of the machines, which is a result of the limit placed on the diameter of the revolving portions by the high speeds of revolution, and in consequence it becomes necessary to make the maximum possible use of the space in the rotor which is at the designer's disposal.

The material which has to be got into this space may be classified as follows :—

1. Iron to carry the required flux.
2. Copper to carry the required magnetising current, with the necessary insulation.
3. Area to carry air ventilation.
4. Materials included for mechanical purposes only.

The correct proportioning of these various parts with a view to a maximum of effectiveness and a minimum of cost, both for labour and material, is the problem that the designer has to face. The output of a given design may be regarded as directly proportional to the first of these, namely the iron, and nearly proportional to the second, the copper, so that if these can be increased at the expense of (3) and (4) a valuable saving may result. This has been effected in many cases by providing artificial ventilation for cooling the iron and copper of the stationary element. The ventilation scheme which some makers have adopted is to provide a centrifugal fan at each end of the rotating element, or to make the rotor itself create the draught. Thus air is driven both round the end windings of the stator and also through the ducts in the iron core, and out through a chimney at the top of the stator casing. In other cases a separately driven fan is provided, forcing air through both the stator and rotor of the alternator. In both these methods, or a combination of them, the extra pressure obtained results in the passing through the generators of large quantities of air, which is often arranged to be drawn from outside the building, so as to be as cold as possible, thus largely reducing the final temperature of the windings.

Among other stations, the Carville power station of the Newcastle-upon-Tyne Electric Supply Company, Ltd., has a ventilation scheme with separately driven fans which were installed to enable the alternators to carry heavier overloads, although in the first instance

the machines were run for some years with natural ventilation, and were well inside the figures guaranteed for temperature rise.

Messrs. C. A. Parsons & Co. have constructed 2-, 4-, and 6-pole rotors of the salient-pole type.

In the smaller 2-pole and 4-pole designs a solid construction with the coils wound in place is adopted. The 2-pole rotor is thus very similar in appearance to the old Siemens shuttle or H-type armature, with which many of us must have been familiar in the early days of electric lighting. The formation is excellent mechanically, since there are few loose parts, and the solidity of the construction enables great mechanical strength to be secured. The rotor body is bored at each end and shaft ends of special high tensile steel forced in, and then the whole turned up and accurately balanced. The balancing is done in three stages before winding the coils :—

1. By ensuring static balance on a pair of carefully levelled knife edges.
2. By careful measurement.
3. By running up to about one-third above normal speed in a specially constructed balancing machine.

The combination of these three methods is essential, since while the balance may be perfect on the knife edges, this may be the result of one end of the rotor being heavy at one side while the other end is heavy on the other. In this case, though in perfect balance on the knife edges, there will be present when running a powerful couple travelling round at the same speed as the rotor and causing vibration. Careful measurement will generally show where weight should be removed or added to give both good static and dynamic balance, which is corrected and improved by actually running and fitting weights as required.

The rotor, after being thus balanced, is put into a horizontal winding machine, and the coils wound into coil cases, which are made of tinned steel and completely soldered up after the winding is completed. The ends of the coil are brought out through a brass lip, soldered into the case, and fitting tightly round the connection to the next coil or to the slip rings, thus making a hermetically sealed coil. Up to the date of writing there has not been a single case among a large number of machines of a coil wound on this system becoming earthed or giving trouble in any way.

A further advantage of coils thus wound and protected is the permanence of the balance of such rotors. Formerly with unprotected coils the windings had to find their own place as they were squeezed up by the centrifugal force, by the sliding of the insulation along metal surfaces more or less smooth. Thus the insulation was sometimes damaged and perhaps one or two coils went further up than others, thus throwing the rotor out of balance. On running again other coils would move slightly, and so the balancing process had often to be repeated several times before a stable condition was reached. With

the metal cases the coils take up their final position at once and stay there, and it is a common occurrence for a rotor to go straight up to 25 per cent. over speed the first time it is turned round without requiring any further balancing. In the case of large rotors the pole-tips are made to slide over a tee-shaped projection on the rotor body, and the coils are wound separately in coil cases and slipped over the poles before the pole-tips are put on.

In selecting material for high-speed work it is particularly necessary that it should be of the best, and it is most desirable not to obtain high tensile strengths at the expense of the ductility of the material; it is rather tempting to do this, since a design can often be materially improved and cheapened by using a large diameter and high peripheral speed, while the factors of safety can be kept high *on paper* by using such material, but it is on the ductility that we rely for properly distributing the stresses between the various parts, while material of too great hardness may easily be cracked or flawed accidentally either during construction or afterwards.

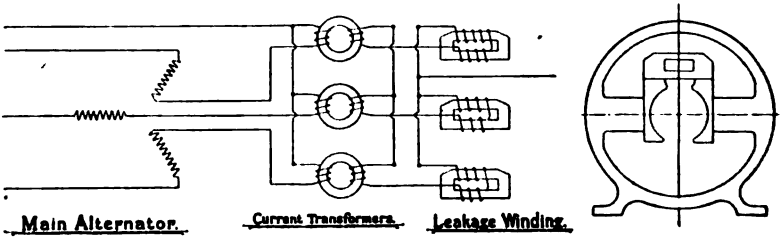


FIG. 11.—Diagram of Connections. Leakage Winding.

As in the case of continuous-current machinery, one object is to get the maximum output at the highest speed possible. The strengths of the materials limit the diameter and length of the rotor and therefore both the available flux and ampere-turns. This again limits in the stator the output for a certain inherent regulation. If, however, any method of compounding the alternator to improve the regulation is adopted, much larger outputs can be obtained from a given carcase. Many methods of doing this have been proposed, but most of them depend on either commutating a portion of the alternating current or causing certain parts to become saturated as the load increases, or by varying the effective resistance of the winding on the exciter magnets. The first is objectionable on account of the trouble given by commutators, the second since the compounding will vary with varying voltage, and the third is generally too slow to allow for rapid changes of load. A method of compounding has recently been brought out (see Parsons' and Law's patents 24141/05 and 13712/07) which avoids these difficulties.

The exciter is provided with an alternative path for the magnetism in

parallel with the armature which we call a "leakage path." This "leakage path" is provided with a winding, which is in series with the stator winding, and as the alternating current in this rises it chokes back the magnetism, or in other words increases the magnetic resistance of the leakage path. Thus more flux goes through the armature and

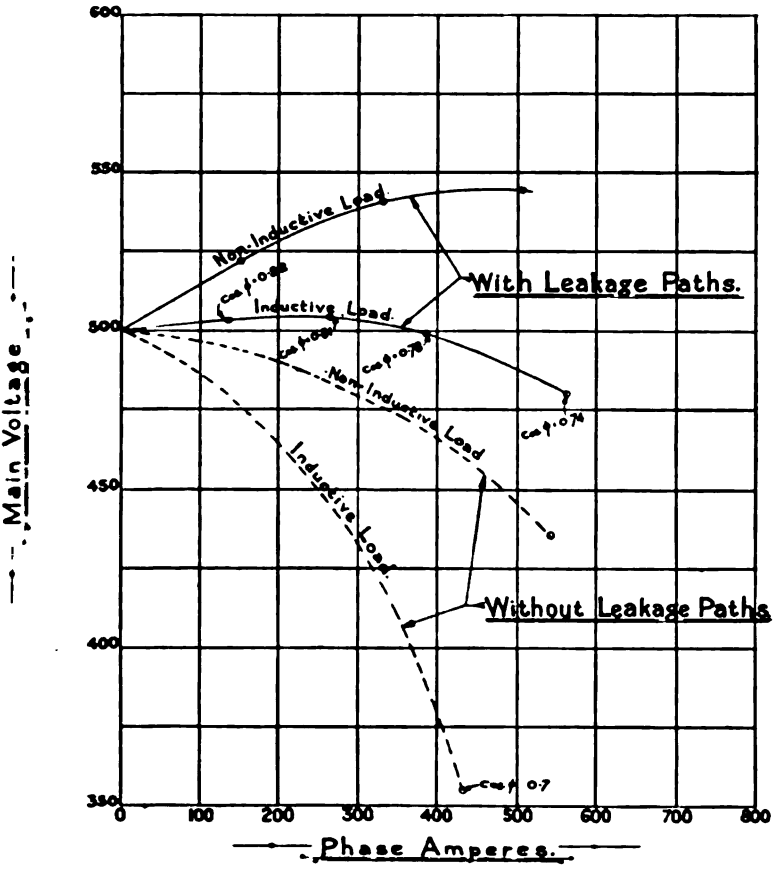


FIG. 12.—450-k.w. Turbo-Alternator Voltage Regulation Putting on Load. Rheostats unaltered.

therefore the voltage of the exciter rises and compensates for the tendency of the main voltage to drop. In a 3-phase alternator there is generally one leakage path in each phase, and if the primary current is at high voltage, a current transformer is generally used. These leakage paths are easily adjusted for any desired amount of compounding; or for any power factor. Fig. 11 shows diagrammati-

cally this arrangement fitted to the exciter of a turbo-alternator, and Fig. 12 gives the comparative regulation on varying load with and without the leakage path in action.

The authors have in this paper endeavoured to trace out the progress of the high-speed dynamo from its first inception by Mr. Parsons in 1884, and to show the difficulties that had to be met at each step before turbo-dynamos and alternators could claim their present commanding position. They have also tried to describe briefly some of the more important features of the modern types and to show the principles on which they have been constructed.

As regards the future, it is hardly possible that progress will be quite as rapid as it has been in the past, but it is certain that still larger turbo-units will be built both for direct and for alternating current, and in their design many problems will be encountered which will demand the highest skill of the scientist and the engineer.

Discussion in London.

Dr. Silvanus Thompson.

Dr. SILVANUS P. THOMPSON: When one looks at this paper, one notices at the outset that it plainly does not profess to be more than an account of the highly successful doings of one firm, that of Messrs. Parsons. And as the subject matter of the paper is confined to the manufactures of this firm and the progress that has characterised those manufactures from the beginning, it would be rather invidious on the part of any one to drag in the products of other firms by way of instituing comparisons, either favourable or unfavourable. If I proceed to criticise the paper in any detail I trust that neither the authors, nor the firm that they represent, will think that I do so in any spirit of want of appreciation, either of the paper or of the years of patient work and advance that the paper represents. For really it is a remarkable advance. I have taken the trouble to analyse the figures of a number of machines so far as they are given, to see what we can infer as to the utilisation of materials, and they show a very remarkable progress in the utilisation of copper and iron in giving their later machines a larger output in proportion to the quantity of material used; in other words, their recent machines in proportion to their output are smaller. I have taken as the basis of comparison the coefficient obtained by multiplying together the diameter and length of the armature core, and dividing that by the kilowatts of output giving the Steinmetz coefficient. Beginning in 1884 with a small 8-k.w. machine (it is described as 10 electrical horse-power), the coefficient 2·4 for a small continuous-current machine; in 1899 it had gone down to 2·1 for a 60-k.w. machine; and in the two recent examples of continuous-current machines of 750 and 1,000 k.w. respectively this coefficient of relative size had further gone down to 0·917 and 0·828—that is, to nearly almost exactly one-third—so that there was three times as much output in proportion to the size of armature, as measured by the product of the diameter and length. Turning to alternators, it is even more striking. The earliest

Dr. Silvanus Thompson.

machine mentioned is a 75-k.w. single-phase machine in 1889, where the ratio is 3·0; a little later in a 150-k.w. single-phase machine the ratio had gone down to 1·76; in 1894, in a larger machine of 350 k.w., the ratio was 2·8; in 1894–96 (the exact date is not given) in a machine of 1,000 k.w. the ratio had gone down to 1·73; but in the most modern machine illustrated in Fig. 9, the 4,000-k.w. 3-phase machine at Carville built, I believe, about 1903, the figure had gone down to 0·64, that is, a little more than one-fifth—five times as much output in proportion to the product of diameter and length. A firm that can do that between the years 1889 and 1903 has certainly made a very remarkable advance. I note on page 289 a comparison between the winding of a ring armature, a Gramme armature, and a drum, which reads as follows: "And since the Gramme armature had twice as many segments as the drum for the same number of conductors it appeared that the result should be better." I venture to think that if the argument had been put the other way round it would have been more cogent, because the important thing is not the number of conductors but the number of segments at the commutator. There must be a certain number, otherwise the commutation would be bad, and for a given number of segments the Gramme armature has twice as many conductors, because it has all the internal ones as well as the external ones; and that will not diminish the self-induction but increase it; consequently it ought to be worse and not better. And so indeed it appears to be, for towards the bottom of the page the chief defects are recognised, the statement being made, "sparking was not reduced owing to the large self-induction of a Gramme winding." I suppose we may take it that this little piece of argument on page 289 relates to bipolar machines. I imagine it does, because at the very top of page 290 there is a reference to "the heating of the spindle due to its revolving in a stationary internal field of the armature." That would be true for a bipolar ring armature, but scarcely for a 4-pole. The internal amount of field through the shaft is negligible in a multipolar machine. Then follows an extremely interesting statement about the use of smooth-core armatures in continuous-current machines, which appear to be still preferred in these high-speed machines to slotted armatures, and the reason given appears to be the better commutation that can be obtained. Is that the only reason? It seems to me that there must be another reason, namely, that with these very high surface speeds, if slotted armatures were used, with slots of the usual sort or size, the frequency of change of magnetism, where the teeth go in and out under the polar edges, would be deleterious. Eddy currents would be set up in the pole-pieces, and there would be a severe iron loss as the result of having this very high frequency change. Surely that is one reason why teeth should be avoided in machines of this type. I understand the figures in the diagram, Fig. 3, of the range of possible brush movement in these continuous-current generators, refer to bipolar machines. Is it not possible that, with multipolar machines, there might have been a better range without any compensation? My

Dr. Silvanus Thompson.

impression is that there would be, even with the high-speed machines, a better commutation with 4-pole machines than with 2-pole machines.

The result obtained by the compensation in giving that broad zone between the upper line marked C and the lower line marked C is very remarkable indeed; it shows that the brushes may literally be fixed and yet a perfect commutation be obtained. I comment for a moment on a line at the top of page 292, where it is claimed that this method of compensating, which has no iron commutating pole, has the advantage that there is no self-induction to cause time lag at sudden changes of load. But it seems to me that if there is a sudden change of load, that will equally affect the current through the armature and the current round the series winding. It cannot increase or decrease in one at a greater rate than it increases or decreases in the other; and though either or both of them may have self-induction, and the increase or decrease as a whole may be retarded by self-induction, still they will both be affected equally, and therefore I cannot see that the self-induction has anything to do with the want of compensation between the two. A detail that is new and interesting to me is the arrangement of the commutator segments so clamped as to admit of longitudinal expansion, mentioned at the bottom of page 295. One end of the commutator has a small cone, so arranged that it has a small amount of liberty to slide along the shaft. I presume there is some kind of spring arrangement to take up that expansion, otherwise the end ring will be liable to part company on contracting if there were no means (apparently none mentioned) for securing a return. I notice on looking at the fine diagram on the wall a slight difference in construction between it and Fig. 9. The pole-tips which slide into the body of the rotating field magnet extend in the wall diagram, something like a foot on each side beyond the end of the armature core. In the diagram in Fig. 9 they extend very little, not more than an inch or two, and it occurs to me to ask whether there is any importance in that. Is it for magnetic or mechanical reasons that the poles are so largely extended? At the bottom of page 301 there is a brief discussion of the relative advantages of having the poles of the field magnet wound each one solidly as a whole, or of having, on the other hand, a winding distributed in several slots; and we are told that "any difference there may be in the two types as regards voltage regulation is certainly small." Is that the whole of what we want to know? In those cases the winding is divided over several slots; the middle region of the pole has more ampere-turns round it than the outlying parts, and the result will be that, even if the air-gap is practically of uniform width over the pole-face, the flux will be concentrated more at the middle of the face than towards the edges, which is good because one desires to have a distribution nearly approaching a sine function of the space. That can be obtained in other ways, and no doubt is partially obtained by the shaping of the pole and by the overhanging of the tips; but is it not true that if the pole is salient, with the winding surrounding the whole, there is greater liability to distortion of the magnetism laterally by the

cross-magnetisation, when there is a large load on, than if the winding were concentrated around the middle portion, so making deliberately a stronger piece of pole in the middle. For, even if the initial distribution of the magnetism at no load is approximately a sine function, then if the disposition is such that distortion by cross-magnetisation is possible, the curve would be sheered over, and the electromotive force curve will no longer be a true sine curve, and the heating in the armature iron will no longer be a minimum. It occurs to me that there must be some advantage in the other form of pole, because there will be less liability to such distortion, and therefore less iron heating at full load. It may not be important, and I only mention it to ask whether it has been proved that, from the point of view of the iron losses at full load, there is not really a difference between these two types. For the method of compounding through the exciter of the alternator I have nothing but admiration, and I need say no more on it. I hope my criticisms may not be regarded as captious. I have the greatest admiration for the work that has been done by Messrs. Parsons and, may I add, by Mr. Stoney, who has had so large a share in looking after the electrical part of the turbine business. I rejoice to be able to say so, because we, as electrical engineers, are glad of any advance, from whatever quarter it may come. We are glad to know of progress made whoever makes that progress; we welcome it if it comes from America, or from Switzerland, or from Germany, or from Italy, or from France. But when we have before us a record of progress made in our own country and by our own countrymen, I think we ought not to be behindhand in expressing our congratulations to them. Dr. Silvanus Thompson.

Mr. E. J. Fox: I am sure we must all again feel, after reading the paper, the amount of work that Mr. Parsons and those associated with him have had to do in the development not only of the turbine, but of the necessary electrical generators for coupling to them. Mr. Parsons and his associates have developed the two together, and the difficulties they have had to face would probably have disheartened most people. Some four or five years ago, when Messrs. Willans and Robinson first took up the manufacture of steam turbines, they were in a difficulty because no suitable generators were available for coupling to their turbines. All those manufacturers who had already built machines of this type had their own fish to fry, and built generators for coupling to their own turbines. The result was that Willans and Robinson had to persuade some of their electrical friends to take up the manufacture of this class of generator, and the few remarks and criticisms I would like to make this evening are based on experience which we have had with different types of generator built by different makers. In the first place I am sorry that the authors confine the description of direct-current generators to smooth-core machines with "corrugated" commutators. I know that machines of this type have in the past done, and still are doing, excellent work, but I think the standard is a low one, and that more modern designs should be aimed at. The smooth-core armature and the type of commutator described Mr. Fox.

Mr. Fox. in the paper will, I am sure, have to give way to the slotted-core machine and commutator with carbon brushes, if direct-current turbine sets are seriously to compete with reciprocating engine sets. First of all, as far as smooth-core machines are concerned, surely they cannot be called mechanical. The conductors, which must be laminated, that is made up of small wires, in order to avoid eddy currents, have to be designed and driven in the same way as smooth-core machines were driven ten or fifteen years ago, namely, by means of driving pegs. Then, again, the conductors require to be laced on to the surface with steel wire, and are liable to shift and to disturb the balance after the generator has been at work and has already been balanced. In short, the construction is unmechanical compared with slotted-core machines. If it were impossible to obtain a different type of machine for running at these high speeds, well and good. There is no disputing that this type of machine often runs well, and, as the authors have told us, the commutation is in many cases excellent, but what is the objection to the more mechanical design made possible with slotted-core machines? I refer more particularly to the type of direct-current dynamo that Willans and Robinson have to some extent been responsible for introducing into this country—I am sorry we have had to go abroad for them—that is, the type built by Brown-Boveri & Co. I am of opinion that no direct-current dynamo built elsewhere at the present time will compare with the type and design which Brown-Boveri & Co. have developed. That type of dynamo will enable a turbine, from the smallest sizes upwards, to compete with reciprocating engine sets and at a saving in capital cost to the purchaser, and what is the objection to that type, in comparison to the more unmechanical type described by the authors? The authors tell us that the objection is that such good commutation is not obtained. That, however, is not the case. I know that in the case of turbines we have installed with the slot-wound type of dynamo that the commutation is as good as possible. In principle it seems to differ from the authors' designs (outside the question of smooth core *versus* slotted core), principally in that in addition to the compensating winding there is a commutating pole. It would seem as if that was a natural sequence of events. A commutating pole saves copper on the compensating winding, in so far as the air path is considerably reduced; and, further, it gives a commutating field just where it is wanted, instead of an undefined field unguided and out of control.

Leaving the armature and coming to the commutator, I am sure that the corrugated commutator with wire brushes is bound to die a natural death before long. The only reason that wire brushes are used is, that if the commutator itself gets out of balance it does not matter, or it does not matter to the same extent; and it is known that the difficulties of using carbon brushes by themselves, without the assistance of metal brushes, is that commutators, as built at present, are liable to get out of balance when they warm up. The continual heating and cooling throws the commutator out of balance, and then a

chattering is set up on the brushes and commutation is destroyed. So that it is necessary, for the time being, to fall back on metal brushes assisted by carbon tips for cleaning and for lubricating the commutator. This is the standard practice adopted by Brown-Boveri and others, and has the result of giving satisfactory commutation. I was looking at some drawings a few days ago of a special type of commutator with which Messrs. Brown-Boveri & Co. are experimenting, and which aims at working with carbon brushes alone, by introducing a commutator which is free from the ordinary expansion troubles. If this experiment proves satisfactory a great advance will have been achieved in the direction of making possible the use of carbon brushes. The whole turbine industry has been waiting for a satisfactory direct-current dynamo, and I am sure that if other firms will follow what Brown-Boveri & Co. have already done on the Continent there will be a large field for direct-current turbine sets, from the smallest size, say 500 k.w., upwards, and that this type of prime mover will have little difficulty in competing against reciprocating engines. Dealing with the subject of alternators, the authors touched on the salient pole versus the cylindrical type. I am entirely in agreement with the authors here. They have adopted the salient-pole type of machine, and from our experience with this type it leaves little to be desired. The salient-pole generator has perhaps these two advantages over the cylindrically wound machine: first, that better regulation is secured, and, second, that one can work with heavier overloads, due to the greater amount of copper that it is possible to carry on the rotor. Just one final remark on the subject of alternators. The authors advocate compounded alternators. It seems to me there have been a good many alternators of this type brought out which have been discarded, and I think the solution of the alternator problem is an ordinary alternator without any of the complications of compounding; and if closer regulation or closer voltage are required, then a Tirrell regulator will give the required results.

Mr. Fox.

An ordinary alternator plus a Tirrell regulator will do all that is required, and is a good deal simpler than a compounded alternator.

Mr. W. PARKER: The authors have dealt with the historical development of the direct-current turbo-generator, and I should like to make a few additional remarks from the point of view of the history of the development of direct-current machines in general. They recommend in their paper metal brushes and smooth cores, but if one goes back to the early stages of the electrical industry (I refer more particularly to that period when bipolar machines were at the height of their popularity) one finds that metal brushes and smooth cores were used exclusively on direct-current machines. In spite of the fact that these machines were used for lighting where a steady load obtained, and that they ran at low speeds, the brushes required a fair amount of attention to keep them running sparklessly. With the advent of traction, however, where fixed position of brushes was demanded with rapidly fluctuating loads and overloads, it became

Mr. Parker.

Mr. Parker. obvious that metal brushes were incapable, unaided, of dealing with the new conditions.

Carbon tips in advance of the metal brushes were tried, to take up the sparking. While this produced some improvement it soon became obvious that this device was not sufficiently drastic. Something new was absolutely essential, and this was discovered in the exclusive use of the carbon brush, the enormous advantages of which were speedily realised, not only by the manufacturer, but also by the user. In such wise was the carbon brush established. The smooth-cored armature was also abandoned, and slotted cores took its place as carbon brushes rendered the use of this immensely superior form of construction possible.

Now, in view of the fact that smooth cores and metal brushes have been definitely abandoned in slow-speed machines, it comes as a surprise to me to find the authors still advocating this antiquated construction in a type of machine where commutation difficulties are much more severe then in the slow-speed machine, and where, owing to the enormous centrifugal forces, it is absolutely necessary to construct an armature where the winding cannot possibly move, as otherwise the armature will rapidly go out of balance and vibration will begin. There is no doubt in my mind that the user will in the near future insist on slotted armature cores and carbon brushes. This fact Messrs. Siemens Bros. speedily recognised, and with the exception of the first one or two machines slotted armature cores and carbon brushes were used, and they have now in successful operation machines varying in output from 400 to 750 k.w. where this combination is in use.

When the question of constructing direct-current turbos with carbon brushes was seriously taken in hand, it was found that the vibration difficulties could be overcome with a suitable brush holder, but that the real difficulty was the excessive heating of the commutator. In order to overcome this difficulty it is absolutely necessary to cool the commutator artificially, either by channels arranged along the axial length of the commutator segment through which a stream of air is forced by means of a fan on the shaft (which arrangement is the one adopted by Messrs. Siemens Bros.) or by delivering a stream of air on to the commutator surface by motor-driven fans fixed in the basement with the other auxiliary machinery, or in some other suitable manner. With the method of cooling adopted by my firm, namely, axial holes in the segment, the temperature rise of the commutator can be kept down to about 40° Fahr. with a density in the brushes of about 45 amperes per square inch, the brushes used being those of Le Carbone's "X" or "Z" qualities. Moreover, the commutator is no longer than with metal brushes owing to the larger arc of contact possible. I may also say that it is within my knowledge that one of the largest firms on the Continent who have built more than one hundred direct-current turbos have now gone over entirely to the use of carbon brushes. Slotted cores they have always used.

Mr. Parker.

The authors advocate the use of compensating windings only, and they give as their reasons that sparking at the brushes with sudden variations of load often takes place with commutation poles, that the risk of flashing over is largely increased in consequence, and further, that machines with commutating poles spark at some loads and not at others. These statements are absolutely incorrect with a properly designed commutation pole system, as I have seen many machines fitted with commutating poles which ran absolutely sparklessly from no load to large overloads. I have also seen the full-load current suddenly removed by means of a circuit breaker, and it was impossible to say whether the load was on or not. The authors also state that the advantage of using compensating windings only is still greater when machines are required to give varying voltages. This statement also is incorrect, as many machines built by my firm have been run with full-load current at all voltages, from zero up to full normal working voltage, without any sparking. In fact all direct-current turbos built by my firm are tested for commutation on short circuit as this is much more convenient for the test house, and we find that, provided the machine commutes sparklessly on short circuit, it will also do so for any voltage up to the normal rated voltage.

There is one grave disadvantage in the use of compensating windings only, and that is a tendency to flash over, owing to the large excess of ampere-turns on the field system over and above the armature ampere-turns, which produces a distortion of the magnetic flux probably worse than if no compensating winding had been used. There is no doubt that a combination of commutation poles and compensating winding is the best method to adopt, as this is becoming practically universal, not only in England, but with all the leading firms on the Continent.

It does not appear from the paper that the authors have ever tested a machine fitted with a combination of commutation poles and compensating windings, and I think if they were to do so they would speedily alter their opinion.

Dr. Pohl.

Dr. R. POHL: The discussion must naturally turn mainly on the latest construction of Messrs. Parsons, and if the few remarks I make are critical, I am sure the authors will remember that they are merely intended as a friendly interchange of opinion. The main factors of Parsons' latest direct-current machines agree very well with those which I recommended in my paper * before this Institution a few months ago, the only difference being that the voltage per segment is about 50 as against 40 volts. The main features of Parsons' direct-current machines are the over-compensating winding, the bipolar construction up to very large sizes, the smooth core and the metal brush, and the corrugated commutator construction. Three of these points previous speakers have already alluded to, and I wish to associate myself with the opinions expressed by them. I believe that the smooth core will have to give way in a very short time, and also the metal

* *Journal, Institution of Electrical Engineers*, vol. 40, p. 230, 1007.

Dr. Pohl. brush and the corrugated commutator. As regards the over-compensating winding, I wish to say that I quite agree with the speaker who pointed out that the field distortion is by no means eliminated. As a matter of fact, if the design of the 750-k.w. generator is worked out and the field distortion calculated, it will be found that it is just about twice as great as the field distortion would be, if there were no compensating winding at all. I do not mean to say that in Parsons' machines there is quantitatively a great distortion. It is artificially kept down by employing this smooth core which involves a very big air-gap. This, I believe, is the real reason why Mr. Stoney advocates a smooth core. If he would concentrate the greater part of the compensating winding in the neutral zone, leaving only so many ampere-turns in the pole-faces as are required to prevent field distortion, he would find that the slotted core, with the very much smaller air-gap, would give better results, and at the same time save a great amount of field copper. With an over-compensating winding, which has the tendency greatly to increase the field distortion, he is compelled to maintain the present construction of large air-gaps and smooth cores. The second portion of the paper dealing with alternating-current machines is very interesting reading, as it contains one or two points which are distinctly novel. The first is the winding of the coils in coil cases and the hermetical sealing of the cases. I should like to have had a more detailed description of how this is carried out. I do not see how slipping of the coils inside the coil cases is prevented, and I also do not quite realise the way in which the coil cases themselves are secured. The second part of particular interest in the portion of the pages dealing with alternating currents is the leakage path described on page 305. I think Mr. Law's idea is very ingenious, and I wish to congratulate him on it, but at the same time I have some doubts as to whether it will work out in practice as a commercial success. If one looks at the curves in Fig. 12 it will be seen that, in order to maintain approximately constant voltage, an increase of the flux of about 60 per cent. is necessary with an inductive load of 0·8 power factor. This would mean that the total excitation must be increased in the ratio of approximately 1 to 2, or an enormous flux, comparatively speaking, must pass through that leakage path. There is another consideration: Assume the leakage path is completely saturated, the density being, say, 24,000 C.G.S. units, even then the permeability of the material is somewhere between 30 and 40. Assuming that the leakage between the pole-tips without any such leakage path is 5 per cent., then the leakage which is left, even at the highest density, will be between 150 and 200 per cent. In other words, it seems to me that the exciter equipped with such a leakage path will have a field system about three times as large as that of an ordinary exciter. I do not know whether I have made a mistake in working this out, but it seems to me that that is about the case. There is, further, the additional expense of the choking coil and of the current transformers, and I have some doubts whether that expense will be compensated for by the saving in the construction of the alternator. However that may

be, I consider the idea an excellent one in principle. Whether we are critical towards the paper or not, I think there is one point on which we all agree, and that is that we have to be thankful to the firm of C. A. Parsons & Co., and to Mr. Stoney and Mr. Law, for putting these latest types before us, and if other firms would follow their example it would lead to a more complete intercourse and exchange of opinions. In this way I am sure the manufacturers would not only help themselves, but it would be a great benefit to the electrical industry as a whole. Dr. Pohl.

Mr. FRED H. CLOUGH: I should like to criticise the opinion expressed by the authors that the salient-pole type of alternator is the preferable one, more particularly as, with the present tendency to high speeds, such rotors have to be built for either 4 or 2 poles. A 4-pole rotor of the salient type may be considered as having four large slots, necessitating that the exciting winding is in the form of a coil of large cross-section, from which it is difficult to dissipate the heat, and further large bending stresses, due to the size of the slot, occur in the overhung portions, which stresses usually limit the peripheral speed at which the machine can be run. Mr. Clough.

Dr. Thompson has spoken of the distribution of flux round the periphery. With a definite pole machine this could be made practically anything that may be desired.

With a purely cylindrical rotor, if advantage is to be taken of the space available round the periphery for the exciting winding, there will only be a small portion in the centre of each pole which will not be wound, and as a consequence a peaked wave of flux distribution will be formed, giving a high density in the centre of the pole. With the stator winding distributed in a large number of slots, the higher harmonics induced in the individual conductors by a flux distribution—which differs considerably from the sine wave—are practically eliminated, due to the conductors in slots which do not occupy the same position in the periphery being connected in series. Consequently, practically any form of flux distribution can be made use of, and in order to reduce the tooth losses a flat-topped wave having practically uniform density across the pole-face is preferable.

The British Thomson-Houston Company has recently made some machines, having what may be considered as a modified cylindrical type of rotor. In these rotors the diameter at the pole is rather greater than it is between poles, and consequently, due to the reluctance at the pole-face being less than it is between poles, a more uniform distribution of flux can be obtained than with a purely cylindrical rotor, that is, one having a uniform air-gap.

Another and more important advantage of this construction is that this slightly increased diameter of the pole-face allows room for a much heavier retaining ring for the end windings than is otherwise possible, and this thicker ring, having sufficient stiffness, can be fixed to the end of the rotor, and requires no internal supporting spiders. As a consequence of this, the end windings can be very readily venti-

Mr. Clough. lated, and also air for ventilation can have ready access to the interior of the rotor. A speed of 300 ft. per second, which is considerably higher than the machine shown in Figs. 9 and 10, has been obtained with this construction with comparatively low stresses, and due to the efficient ventilation the temperature rise obtained was quite low, in spite of the very high densities which were used.

Mr. Walker. Mr. MILES WALKER: I think that the cylindrical type of field magnet is better than the salient-pole type for the following reasons: (1) A winding distributed in slots affords more cooling surface than the coils on salient poles. (2) The teeth constitute a pole which is much shorter than the usual salient pole, and consequently the leakage is much reduced. (3) There is a marked difference in the characteristics of the saturation curves of the two types of machine. Fig. I shows

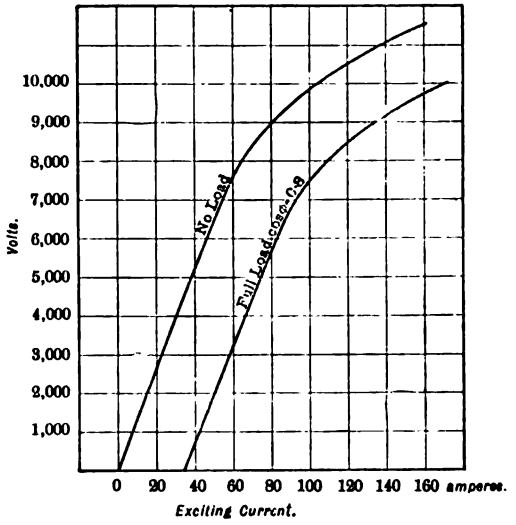


FIG. I.—Cylindrical Field Saturation Curves.

the type of curves obtained with a cylindrical magnet, and Fig. J shows the curves of a salient-pole machine, designed to have the same air-gap and initial saturation. It will be seen that the no-load curve in Fig. J bends over more than that in Fig. I in the upper part. This effect is much more marked in the 0·8 power-factor load curves. A cylindrical field with a saturation curve like Fig. I can be more safely operated at 10,000 volts than the salient-pole type Fig. J at 9,000 volts, and the regulation in the former case is very much better. (4) The winding space is better utilised, there being very little room wasted in supports. (5) It follows from this that a cylindrical field of given output is smaller in diameter, resulting not only in a saving in material but also in a gain in efficiency. (6) A cylindrical field of large output can be run at a

higher speed resulting in a saving in steam consumption. (7) By the use of a bar winding and suitable end connections as shown in Fig. K it is possible to make a winding which is very strong mechanically and Mr. Walker.

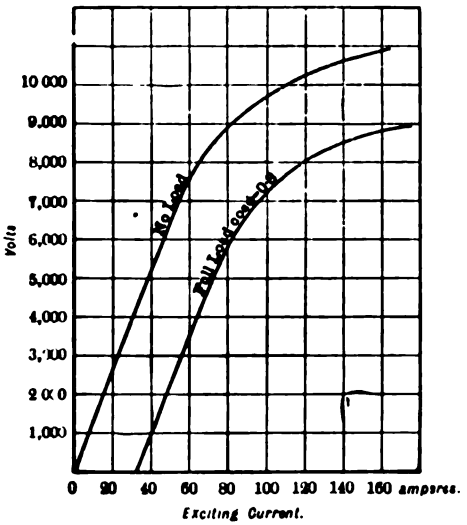


FIG. J.—Salient Pole Saturation Curves.

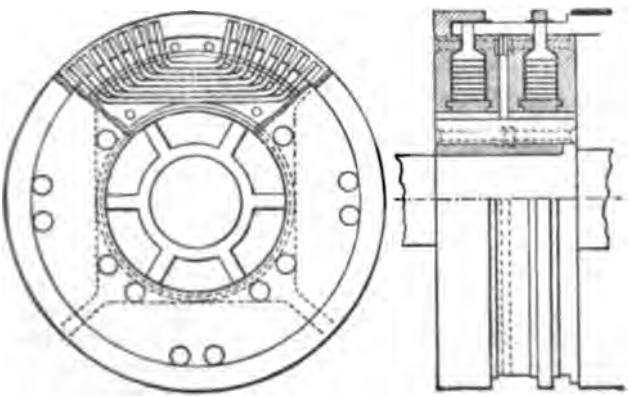


FIG. K.

little liable to get out of balance. Such a winding would enable 60,000 ampere-turns to be put on a 2-pole field only 20 in. diameter, which, at a speed of 3,000 revs. per minute, would give an output of 2,000 k.w. (8) Cylindrical fields ranging in output from 500 to 4,000-k.w. capacity have been constructed so as to embody the method of compensation

Mr. Walker. described on page 432 of vol. 34 of the *Journal* of the Institution of Electrical Engineers. Such compounded alternators have the advantage over other types which depend on the strengthening of the field current in that they are instantaneous in operation. Full load can be thrown on suddenly without making lamps in circuit blink. Moreover, they can be run in parallel with poor regulating machines without any complications, and have the effect of improving the regulation of the whole station.

Mr. Hobart. Mr. H. M. HOBART: On page 306 the authors state that they have endeavoured "to show the difficulties that had to be met at each step before turbo-dynamos and alternators could claim their present commanding position." I agree with the appropriateness of the expression "their present commanding position" as regards alternators, but not as regards continuous-current turbo-generators. While alternators for turbo-driving have been a magnificent success, continuous-current turbo-generators have been, and still are, a dismal failure. We have heard the opinions of three leading manufacturers of continuous-current turbo-dynamos, and they are not in accord even as to the type of brush. One swears by the copper brush without any modification; the other swears by the carbon brush without any copper; and the third employs a carbon tip and copper main brush. It is very far from finality, it seems to me. There are reasons for this circumstance. We can overcome the reactance voltage and armature interference by compensating windings and by interpoles, and both of these methods are fairly satisfactory, but they do not affect the peripheral speed, and that is the cause of the chief remaining troubles. These are mechanical troubles, namely, to find a brush that will work smoothly with peripheral speeds of 30 to 40 metres per second. It seems to me that the reason we have not yet attained any suitable degree of success with large continuous-current turbo-dynamos is that we are going contrary to fundamental laws. The reason we have attained such great success with large high-speed alternators is that we are working in accord with fundamental laws. All who have done any considerable amount of designing, know that the properties of alternators come out better the higher the running speed for which we design them. This can, of course, be overdone, and is a little overdone, with turbo-driven alternators. I would like to see the speed dropped a little, even at the expense of steam economy. The reverse is the case with continuous-current dynamos: the slower the speed the better will be the properties of the continuous-current dynamo. Why not be satisfied with that, and have a good continuous-current dynamo at low speed; or, if one does not want to go too low, why not employ good medium-speed engines? There is another reason for doing so, and that is that the turbine does not show up favourably in comparison with the reciprocating engine, so far as relates to steam consumption, on machines of less than some 2,000-k.w. rated output. It happens that we rarely require continuous-current generators in sizes above 1,000 k.w. Where the turbine is far better than the piston engine, it is in very large sizes

indeed. There are now being built 10,000-k.w. alternators, driven by steam turbines, and they will show far greater economy than can be obtained by piston engine driven sets. In fact, that would not be a good size of piston engine to employ in any case; therefore the alternator and the turbine work in splendidly together. When we come to little sets such as we should want for continuous-current dynamos, I consider that we should employ piston engines up to 2,000 k.w., since we cannot build good turbo-dynamos for much more than 1,000 k.w. for pressures of 500 volts. The present limit for 250-volt turbo-dynamos is more of the order of 500, or possibly 750-k.w. rated capacity. In the most interesting paper before us we find no mention of any dynamo of any such size as 500 to 1,000 k.w. for less than some 500 volts, and I doubt whether many firms are turning out satisfactory 250-volt dynamos of more than 500-k.w. rated capacity. The best plan is to take medium-speed engines for driving continuous-current dynamos and to employ turbines for driving large alternators. Mr. Hobart.

Mr. R. LIVINGSTONE (*communicated*): The authors of this paper have been so closely identified with the development of high-speed machinery that the history of this development, as sketched in the paper, is of considerable interest, and the opinions expressed of the greatest value. Near the beginning of the paper it is mentioned that high carbon steel was used for the very early machines, and the reason given for its use is its great strength. Very often the high tensile strength obtained from the use of a high percentage of carbon involves a sacrifice of ductility, and this sacrifice of ductility in a shaft undergoing many hundreds of reversals of stress per minute is a very serious matter. A high carbon steel with a large elongation and reduction of area is certainly the best class of steel to use, but a high carbon steel with a poor elongation and reduction of area is to be avoided. A more important item in the chemical composition is the percentage of phosphorus. This is a most objectionable element in the steel used for high-speed generator shafts, and should be kept below 0·05 per cent. The physical properties which I specify for high-speed turbo-alternator shafts are as follows:— Mr. Livingstone.

Ultimate strength	78,000–84,000 lbs. per square inch.	
Elastic limit	... 44,000–50,000 „ „ „	
Elongation	... 29 per cent. to 35 per cent.	in a test-piece, 2 in. long by 0·798 diameter.
Reduction of area	55 „ „ 60 „	

No difficulty has been found in obtaining the above figures, although the reduction of area may be considered rather high.

The most important factor in determining the diameter of the shaft, however, is the allowable deflection of the rotor. Care should also be taken that the whirling speed of the shaft is not too close to the normal running speed. The stress to which the shaft is subjected depends to a large extent on the deflection, so that the modulus of elasticity is also an important item.

Mr. Livingstone.

The shrink-ring type of commutator is undoubtedly the best construction which has been introduced so far for high speeds. An important point in designing this type of commutator is the longitudinal expansion of the copper. A good way to take care of this is to connect the two centering rings by light turned-down bolts. These bolts stretch when the commutator expands and act as a strong spring.* This construction, however, is only possible in commutators for large machines.

The smooth core drum armature is undoubtedly good from the point of view of commutation, but it does not appear to be so satisfactory a mechanical construction as the slotted armature. I should like to ask the authors if any serious movement of the winding takes place in the smooth core armatures when the machine is short-circuited. This would appear to be the only thing to fear with this construction. Steel binding wire is the best wire to use for high-speed armatures, but I do not think the increase of strength is so great as is popularly supposed.

The initial stress in the wire due to bending when wound on an armature is much higher in the case of steel wire than it is in the case of phosphor-bronze wire, so that although the steel wire is double the strength of the phosphor bronze, yet we cannot use half the number of turns if we wish to keep the same factor of safety. This is particularly the case with large wires wound on a small diameter of armature. For example, assume that we have a 30-in. armature and that we wish to use 0·049-in. diameter wire with a factor of safety of 3. Then with steel wire we have a bending stress of 41,000 lbs. per square inch and with phosphor-bronze wire a bending stress of 18,200 lbs. per square inch. With an ultimate tensile stress of 250,000 lbs. for steel wire and 120,000 lbs. for bronze wire we have then an allowable tension stress of 42,000 lbs. per square inch for steel and 22,000 for phosphor bronze; so that in this case the steel wire has 1·9 times the strength of the bronze. With 0·072 diameter wire, on the same armature and using the same factor of safety, we find an allowable tensile stress of 23,300 lbs. per square inch for steel and 13,000 for bronze, so that in this case the steel wire has only 1·78 times the tensile strength when wound on the armature. The factors of safety I have taken may appear low in comparison with the usual factors of safety but it must be remembered that this is a *real* factor of safety, when one takes account of both bending and tension stresses. Again, it is a matter of experience that in the majority of cases of failure of binding wire, it is the soldering between the turns which usually gives way, and, of course, in this case the tensile strength of the wire does not matter. The shearing stress on the solder must be kept exceedingly low, and in some cases will limit the reduction of the number of turns when changing from bronze to steel wire.

Compensated windings appear to be the best way to counteract the

* "Mechanical Design and Construction of Commutators." The Electrician Publishing Company.

effects of the armature ampere-turns, but the ratio of the turns should depend to some extent on the tooth and gap densities, on the ratio of armature to field ampere-turns, and on the reactance voltage. It would be interesting if the authors could give these values and ratios in the case where it was found that a compensated winding, having 1·4 times the armature ampere-turns, was necessary. In the rotor construction shown in Fig. 10 bolts are used for attaching the field-coil supports to the rotor body. This seems to be a weak point in that construction and will necessitate very careful tapping of the holes. If one of the holes is tapped a little bit out, then on tightening up the bolt a very serious bending stress may be put on it. The reduction of diameter due to the threading is known to weaken a bolt considerably when there is a bending stress being imposed on it. A

Mr. Livingstone.

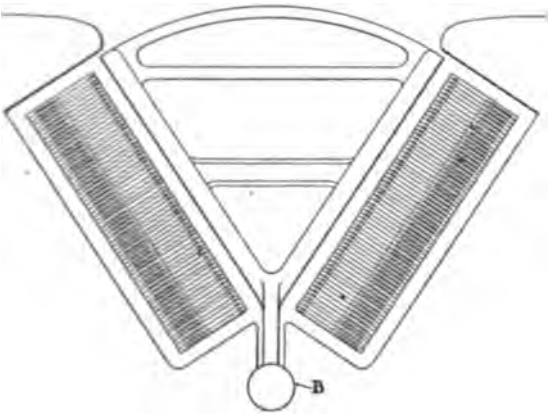


FIG. L.

form of construction which overcomes this defect is one which I introduced in Messrs. Dick, Kerr & Co.'s machines and which is shown in the figure (L).

In this construction the coil support can rock on the pivot (B), and so accommodate itself to variations in the field coil instead of imposing a bending strain at the neck of the support.

The method of ventilating the rotor by having fans at each end adjacent to and revolving with the rotor is of little use in the salient-pole type. In fact, I know of one case where the ventilation was very considerably reduced by putting fans in this position.

The rotor itself is a powerful fan, and unless the auxiliary fans are of as great a capacity they only obstruct the air-passage. The simplest and the best way is to instal a separately driven auxiliary fan, the air from which is led into the end shields of the alternator, and which works in parallel with the rotor acting as a fan.

DISCUSSION AT NEWCASTLE-UPON-TYNE, APRIL 6, 1908.

Mr. Holmes. Mr. J. H. HOLMES: I think that with reference to Mr. Parsons' patent in 1884 hardly sufficient justice has been done to this gentleman, as this was the first indication of the barrel winding which has since come into such prominent use. With regard to the experiment in 1885 on compensating winding, I do not altogether agree with the paper that the fault was entirely due to insufficient ampere-turns. I think it

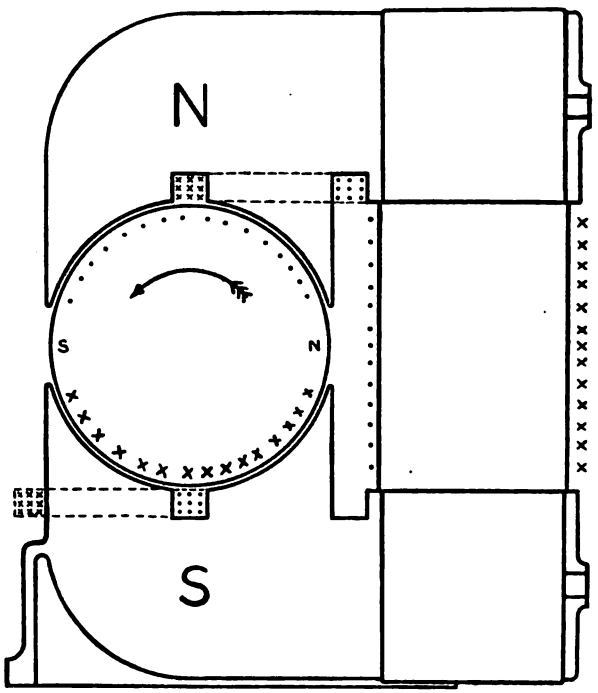


FIG. M.

may also have been due to ineffective design. In 1889 I was personally looking into this problem, and constructed a machine which was fitted with a compensating winding and gave perfectly satisfactory results. In order to neutralise the cross-exciting tendency of the vertical band of armature conductors, I placed a slot in the pole-faces and filled it with ampere-turns, giving an equal and opposite cross-flux. As it was mechanically difficult to make a single coil of this winding vertically, I placed coils on the side of the limbs, as shown in diagram Fig. M, and found I had not only got a neutralising effect of cross-turns, but could so shift the flux lines through each pole-face that it was automatically strengthened and weakened under the leading

and lagging pole-tip precisely in the way that was necessary to gain good sparkless commutation. If some such principle had been applied instead of the arrangement shown in Fig. 2, perhaps the result would have been better. Mr. Holmes.

With reference to brass-wire brushes, this point is interesting, as lately carbon brushes have been used, and also I think the Westinghouse Company have been placing brushes sideways so as to avoid jumping. The Morganite Company have also introduced a pneumatic brush-holder which I have heard is satisfactory. The paper mentions the balancing of armatures on knife edges, and I have recently been at one works where, instead of the knife edge, there was a surface 6 in. wide, carefully planed up and kept level, the idea being that in the knife edge the surface of contact is so small that the weight of the heavy armature would cause the metal to sink in and thus prevent the armature from rolling well.

Mr. TURNBULL: What is the effect of the magnetic shunt on the commutation of the exciter? Mr. Turnbull.

Mr. DAVIDSON: It is important to arrange the exciter and leakage path so that when no current is passing round the leakage windings, the two limbs are saturated, as the action of the leakage path depends upon this. Mr. Davidson.

In Messrs. Parsons' usual type of exciter, having a simple surface-wound Gramme armature, the air-gap varies from $\frac{3}{8}$ in. to $\frac{5}{8}$ in., and under these conditions an induction of about 19,000 lines per sq. cm. can be obtained in the limbs of the leakage paths. The windings on the leakage paths are arranged as if they were wound continuously round a ring.

When an alternating current is passed through the windings shown in Fig. 11, the flux in one limb at any moment—for instance, take the upper limb—is reduced to zero if the ampere-turns are sufficient. At the same time the induction in the lower limb is not seriously increased; it may rise to 20,000 or a little more, so that about one-half of the original leakage has been destroyed by the alternating current. The exciter magnets being relieved of this leakage flux, the shunt coils are able to send a greater flux through the armature, and the voltage of the exciter consequently rises. In the case of the first alternator fitted with leakage paths, the exciter voltage rise, on putting on full load on the main dynamo, was about 15 per cent., but in later machines we have been able to get a rise of 60 per cent. This, of course, means that, within limits, an alternator can be designed for comparatively bad inherent regulation, as the leakage paths can be arranged to compound to any desired extent.

It will be seen from Fig. 11 that, with the leakage paths removed, nothing like full inductive load could be put on the alternator when the rheostats were untouched. With the leakage paths working the voltage kept up very well. Just recently still better results than those given have been obtained.

These leakage paths have been fitted to about a dozen alternators

Mr. Davidson. so far, ranging from 200 k.w. to 750 k.w., and all the machines are working very satisfactorily on their station loads.

The presence of the leakage paths has been found to have no effect whatever on the commutation of the exciter.

An interesting experiment was made on a 500-k.w. alternator. An incandescent lamp was arranged across the terminals, and placed in a dark room. When full load was thrown off and on the machine, the leakage paths were so rapid in their action as to be practically instantaneous in their effects, and no flicker could be observed in the lamp.

There would appear from the figure to be a great scope for the use of leakage paths, and I think Messrs. Parsons may be congratulated for having devised so simple and effective a method of compounding alternators.

Mr. Longman. Mr. R. M. LONGMAN: I should like to hear Mr. Stoney's opinion of the Morganite Company's pneumatic brush-gear, now fitted to one or two turbo-dynamos, and also his views on the radial brushes lately used by the Westinghouse Company, and whether any trouble was experienced on this type of commutator due to end play of the generator?

Referring to the compensating device, does the extra magnetic leakage path across the top side of the exciter poles affect the commutation?

I should be glad if the authors would give an explanation of the currents in the shaft and bearings of alternators, and the consequent need of carefully insulating one bearing pedestal. The two alternators for the Sydney Tramways are called 5,000-k.w. machines; they are guaranteed to do 6,250 k.w. continuously and 7,500 k.w. for two hours. What is their correct rating?

Mr. Barbour. Mr. R. H. BARBOUR: I should like to have one or two electrical and mechanical details of construction cleared up. I should like to know whether the steel rings are sufficient for keeping the commutators quite true? I should like to have details of the wear of brass or copper brushes and of the commutators. The shaft shown in the latest machine illustrated is discontinuous. Is it not difficult with such shafts to make the machine run true?

Mr. Hunt. Mr. F. O. HUNT: With reference to the use of steel for binding wire, has manganese steel, having non-magnetic properties, ever been tried? I should also like to know why there should be an anticipation of difficulty in running self-excited compensated dynamos in parallel?

Mr. Stoney and Mr. Law. Mr. G. STONEY and Mr. A. H. LAW (*in reply*):—The remarks of Dr. Silvanus Thompson on the utilisation of materials in modern designs are interesting as showing the improvements that have been effected. At the same time, of course, owing to the larger outputs of modern plants, one would expect the size constants to be a good deal less. As a matter of interest, on recently going into the design of the first Parsons' turbo-generator constructed, and illustrated in Fig. 1, we

have come to the conclusion that it would be difficult to improve on the design, having regard to the high speed at which it was then necessary to run. Mr. Stoney and Mr. Law.

He also called attention to an incidental advantage of the smooth-core armature, namely, that it reduces the heating in the pole-pieces and also eliminates the iron losses in armature teeth, and there is no doubt that these points have considerable importance. Another point was that he did not quite understand why there should be time lag in the commutating pole when changes of load occur. It is, of course, a fact that there is no time lag in the current which excites a commutating pole, as the windings are in series with the armature, but time lag will occur in the flux produced by these windings, and it is this flux that is of importance in preventing a disturbance of the commutation.

With regard to the fastening of the commutator, a spring washer is provided between the nuts and the cones supporting the commutator, to allow for expansion and contraction, and to keep the commutator firmly pressed towards the body of the armature. This washer can just be seen in Fig. 4. In reference to Gramme armatures, all the early ones of this type were bipolar.

The extension of the pole-tips in Fig. 9 is for mechanical reasons only. The 4,000-k.w. plant shown in Fig. 9 has these projections held down by non-magnetic end caps. In some modern plants these projections are made somewhat longer and are held down by massive bolts.

With reference to rotors of the salient-pole and the cylindrical types, we have constructed rotors of both types, and it is not our experience that there is any more distortion with one than with the other, but undoubtedly it is necessary in the case of the solid-pole type to shape the pole-pieces suitably.

Mr. Miles Walker pointed out that it was possible to work cylindrical type rotors at a higher flux density than those of the salient-pole type. In most of the designs which we have examined, however, this high density can only be realised at a very local point, and at other parts of the magnetic circuit of the rotor there is quite as much or even more iron for a given flux than with the salient pole. That this density is only local was clearly shown by the shape of the open circuit curve sketched by Mr. Miles Walker.

The advantage is claimed for the cylindrical rotor that the coils can be so efficiently ventilated that the output is largely increased, but this is on the assumption that an equal amount of ventilation can be obtained for the end windings, and considerable difficulty has been met with in the efficient ventilation of these end windings.

Mr. Fox and others expressed the opinion that the smooth core is bound to give way to the slotted core in turbo-dynamos. It is an old argument that the slotted-core armature is a more mechanical construction than the smooth-core with binding wire, but experience obtained with the reliability of the smooth-core type has convinced many

Mr. Stoney and Mr. Law.

engineers who have practical experience of both that in many ways the smooth core is the more reliable of the two.

In the smooth-core armature the windings are assembled over a uniform and easily applied layer of insulation, which covers the whole of the armature core and end drums. Over the conductors a similar layer of insulation is placed, and the whole can be thoroughly examined before the binding wire is put on. A temporary layer of binding wire is first put on, and the armature thoroughly dried. This wire is removed, giving a further opportunity of examining the insulation over the conductors, and finally the permanent wire is wound on. This method contrasts very favourably with the insulation of a coil in a deep slot having numerous more or less jagged edges. In this case it depends on the care taken by the winder, and once the windings are in place any mistake remains undetected until it shows itself in one of the usual well-known ways. It is a matter of experience that with surface wound armatures in sizes varying from 4-k.w. up to 1,000-k.w. *there has never been an instance* of the windings shifting owing to sudden loads or short circuits. It is a simple matter to drive the conductors efficiently with a smooth-core armature.

With reference to the question of smooth *versus* slotted cores, it has often been observed at Heaton Works that amongst the large number of motors which have been installed at various times, the ones which have given the least trouble and which require the least attention have been three old-fashioned Crompton motors with two-pole horse-shoe magnets and smooth-core armatures working with wire gauze brushes on the commutators. Probably the most ardent advocate of the slotted-core armature as against the smooth-core would, as regards commutation, only maintain that the slotted core is "good enough," and never that it was as good as the smooth core.

Reference has also been made by several members to the use of commutating poles, and one argument put forward by Mr. Fox against the distributed compensating winding without a commutating pole is that it provides an "undefined field" for commutation. This is precisely what we consider to be the strong point of the distributed compensating winding since it means that a good commutating position can be found within a large range of brush movement.

It is a significant fact that most firms who started to build high-speed dynamos were in their early days ardent advocates of commutating poles only, but we believe that in every instance they have deserted the commutating pole for a combination of compensating winding and commutating pole. We still maintain that even better results can be obtained by eliminating all the iron between the pole-pieces and obtaining for commutation the "undefined field."

The above considerations lead us naturally to the question of the brushes. It is a little curious that in this discussion the members who have most strongly advocated the use of slotted cores and commutating poles should in most cases also be the ones who seem to find carbon brushes to be the only ones to give satisfactory results. We would

suggest that this is merely an instance of cause and effect. Undoubtedly it is a greater achievement to produce a continuous-current generator that will commutate satisfactorily with metal brushes than to do so using carbon, and one cannot help wondering whether the anxiety of some folk to see every one adopting carbon brushes may not be due to their failure to produce a generator which will give satisfaction with the older form of brush. The fact remains that the two earliest manufacturers of high-speed continuous-current plant still retain the metal brush in some form. The firm with which we are connected have obtained such remarkably good results with large two-pole smooth-core generators that for the present they retain the brass wire brush as the standard. At the same time such improvements have recently been made in the manufacture of carbon brushes that in view of the possibility, or perhaps we may even say the probability of some form of carbon brush being eventually used, the commutators of their machines are designed of such ample dimensions that as soon as carbon brushes become a thoroughly practical proposition the change can be made at small expense. Messrs. Parsons know of about half a dozen dynamos of their construction on which carbon brushes are at the present time giving comparatively good results, and further experiments in this direction are at present in hand. Mr. Stoney and Mr. Law.

Mr. Parker referred to the volts per segment as apparently being the sole cause of flashing over. This is certainly not so, since the only case with which we have come into contact in which flashing has occurred (since entirely overcome by comparatively simple alterations in the generators) the maximum volts per segment does not exceed 40. These were 4-pole plants, and Messrs. Parsons have constructed a large number of 2-pole plants with maximum voltages per segment up to 52 and 53, and with this type have never had an instance of flashing over under any conditions whatever, including practically dead short circuits.

Mr. Parker and Dr. Pohl also referred to the flux distortion on the pole-face caused by the large ratio of compensating used by Messrs. Parsons. In our opinion this distortion does not take place to an appreciable extent, and investigations at Heaton Works with the oscillograph have shown this view to be correct.

Dr. Pohl asked a question as to the winding of rotor coils into metal cases. It has been found possible to do this, and obtain a coil which is so absolutely wedged into its case that movement inside is avoided. Any movement is confined to the coil as a whole, and owing to the armouring of the metal case thoroughly mechanical means can be adopted for securing the coils.

Several speakers referred to the leakage path compounding, and one member referred to the Tirrell regulator. The latter has no doubt given excellent results, but it is found that some direct means of compounding is very much quicker in action, and the method described by us has the advantage that there are no moving parts whatever, so that the action is entirely electromagnetic.

Mr. Stoney and Mr. Law.

As Dr. Pohl suggested, it is of course necessary to make the iron of the exciter magnets rather larger for a given output of exciter, but an increase of, say, 30 per cent. in the iron of the exciter magnets represents a very small increase in the cost of an alternator. An advantage of this method of compounding is that there is no time lag in the exciter magnets, since the flux in the magnets is not increased by the action of the leakage path; the flux is merely diverted from the leakage paths through the exciter armature.

Mr. Livingstone, in his communicated remarks, lays stress on the importance of ductility in steel for high-speed work. We quite agree with his remarks, as will be seen by a reference to page 304 of the paper. Mr. Livingstone asks if any movement of the windings of smooth-core armatures occurs when the machine is short-circuited. As already stated, there has never been an instance of such movement on shifting of the conductors on properly constructed smooth-core armatures. As regards binding wire, Messrs. Parsons use a very large factor of safety, as there is no advantage whatever in cutting this fine.

As regards the bolts holding the coil clamps and the possible bending stresses to which they may be subjected owing to slight inaccuracies of workmanship, this point was foreseen in the very first rotor of this construction, and therefore the underneath part of the bolt head or nut is made spherical so as to give a ball and socket action.

The diagram of an early compensating winding designed by Mr. Holmes is exceedingly interesting, and we are strongly of opinion that, as in the case of the one shown in Fig. 2 of the paper, had he increased the number of ampere turns very excellent results might have been obtained. It would seem that it was only the advent of the carbon brush that prevented a number of such compensating windings having been adopted years ago.

In reply to Mr. Turnbull, the exciter commutation is quite unaffected by leakage paths and their position seems to have very little influence.

Mr. Longman referred to the Morganite brush gear with pneumatic sockets, and of these we can only say that we have no direct experience, but know that it is working very satisfactorily on three turbo-generators of Messrs. Parsons' construction. The question was raised as to the rating of the Sydney 5,000 k.w. alternators, which have to do 6,250 k.w. continuously. In view of the low temperature rise guaranteed (45° F.) at 5,000 k.w., it is probably intended to run this plant at its continuous overload of 6,250 k.w. at times when the atmospheric temperature is low. We have, however, no precise information on this point. The alternator in size about corresponds to one of 6,250 k.w. The probable life of commutators of Messrs. Parsons' plant is found to be from eight to twelve years under ordinary running conditions with compensated dynamos and wire brushes. It has never been found necessary to use an adjustable shunt for Messrs. Parsons' compensating winding, as a winding can be designed which is suitable without adjustment for all conditions of load or voltage.

Mr. Hunt suggests using a non-magnetic [illegible] but we consider it is not at present possible [illegible] wire. Separate exciters are used [illegible] current plants owing to the [illegible] the armatures and the undesirability of running them in parallel without some such arrangement. This has never been found necessary with the Parsons type of dynamo.

As regards [illegible] above speed in Messrs. Parsons' [illegible] house so constructed that should any [illegible] no danger to the attendants. [illegible] happy to say that this [illegible] tested.

At each meeting at which the paper was read a unanimous vote of thanks was accorded [illegible] communicate to the members.

Proceedings of the Four Hundred and Seventy-fifth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 9, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on April 2nd were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Walter Binns.	A. C. Coubrough.
William A. Brodie.	C. C. Garrard.

Cecil L. Sumpter.

From the class of Associates to that of Associate Members :—

Arthur T. Kinsey.	Harold B. Sale.

Charles J. Turner.

From the class of Students to that of Associate Members :—

H. C. Greenwood.	Frank Morton.

Herbert G. Tisdall.

Messrs. W. C. Clinton and W. W. Cook were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Joseph Harding Bolam.	Gilbert Dirk Nelson.
George William Cole.	Joseph Richardson Norris.
Arthur William Mandling.	Arthur Rice, Lieut., R.N.
Harold Ernest Morrow.	Samuel Richards.

Conrad Clemmans Skeates.

As Students.

George Joseph Duckett.	Cyril Arthur Martin.
Albert Neilson Haworth.	Thomas Yewell Porter.
Victor Marcus Levy.	Percy Brice Smith.

Donations to the *Library* were announced as having been received since the last meeting from W. Duane, C. L. R. E. Menges, J. Springer, The Smithsonian Institution, Messrs. Whittaker & Co.; and to the *Benevolent Fund* from The Electrical Engineers' Ball Committee, to whom the thanks of the meeting were duly accorded.

The following paper was read and discussed :—

ELECTRICITY SUPPLY PROSPECTS AND CHARGES AS AFFECTED BY METALLIC FILAMENT LAMPS AND ELECTRIC HEATING.

By H. W. HANDCOCK and A. H. DYKES, Members.

(*Paper received January 28, read in London on April 9, at Dublin on April 9, and at Glasgow on May 12, 1908.*)

It is very satisfactory at the moment to be able to induce a wavering possible consumer to decide in favour of electricity by pointing out that with the new metallic filament lamps two to three times the light can be obtained for the same current as compared with the ordinary carbon lamps which he has used hitherto. He is added to the list of consumers, and the output of the station is increased. He may or may not consume the same amount of current as the old consumers using carbon filament lamps, but he has increased the output of the station. It is also satisfactory when a present consumer replaces a single 16-c.p. lamp with two 25-c.p. tantalum or osram lamps run in series. He gets a magnificent light, and, if he does not do it throughout his house, his bill is not greatly affected.

But what will happen when every consumer uses high-efficiency lamps throughout? Can we feel sure that the only effect will be that the consumer will get more light, and will use as much as or more current than before?

When the gas mantle was first introduced its effect was to give at each burner a greatly increased light for about the same consumption of gas as before. Although undoubtedly one effect was to accustom people to a higher standard of illumination, it was found that the consumption of gas per consumer fell off seriously, and the rate of increase of gas production was checked. Fortunately for the gas industry the change came at a time when electricity for lighting was pushing them hard, and the mantle enabled them to retain, and even to win back, a number of consumers who otherwise would have used electricity; owing, also, to the low cost per service, it did not matter nearly so much to the gas companies if one man's consumption fell off, provided only thereby his neighbour was attracted. The vigorous efforts made by the companies to push gas for heating and cooking purposes (for which they required no additional meters or special rates) also served to stem the ebb tide and prevented the receipts from actually falling off.

In conversation with a number of gas authorities we gather that the new inverted mantle, although nothing like as economical as it is

MPS

rs.

Type.	Percentage saving to Consumer per c.p.-hour.	Percentage Reduction in Current sold by Supply Company per c.p.-hour.	Percentage Increase or Decreased Yield to Lamp Maker per c.p.-hour.
	d.	Per cent.	
Carbon	—	—	—
Carbon	10·50 7·00		[illegible] decrease

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TILDEN FOUNDATIONS.

claimed to be in some quarters, does reduce the consumption of gas per point, and has in places had an appreciable effect on the output of the works.

The present 110-volt tantalum giving 23 c.p., or osram lamp, giving 30 c.p. at a consumption of 40 watts, although they have usually to be arranged in series, might appear to correspond very closely with the original gas mantles in gas lighting.

In some cases consumers will be able to do with fewer points and thus reduce their consumption. In others it will happen that they will improve their lighting, but not very greatly reduce their consumption. Some engineers seem to think the first state of affairs will predominate, whilst others incline to the latter. If metallic filament lamps were always to remain at the present price, and were only available in comparatively large units and at 100 volts, it is probable that the total effect on the station supplying principally private consumers would not be very marked.

The cost of the lamps—4s. for osrams and 2s. 9d. for tantalums—is a very considerable item, and consumers therefore will not adopt them to any great extent unless they can feel assured that their *total* lighting bill will be reduced, or at any rate not increased.

In the case of private consumers, where a large proportion of the points are single lights, with separate switches for each point, the saving in current, if any, with two lamps in series will, except where current is dear, not be great enough to ensure a general adoption of the lamps at present prices.

In the case of shops, halls, and factories it generally happens that the lamps are mostly on all at once, so that the question as to whether a switch controls one or two lamps does not come in. The effect in this case, even if the same total number of lamps be used, is to decrease the current consumption by about one-third, with an increase in the illumination of 50 per cent. or more.

The total saving thus effected, after allowing for the increased cost of lamp renewals, depends on—

(*a*) The price charged for current.
(*b*) The price of the lamps.
(*c*) The life of the lamps.

Table I. gives the total cost of lighting at different prices for current, and at varying lengths of life of the lamps, and at various prices for the lamps. It shows clearly how, at the present cost of the renewals, the saving effected varies as the price for current is reduced.

When lamps are run in series their life depends very much on the fluctuation in voltage on the circuit, and under ordinary conditions it is considerably less than when they are run in parallel. It is claimed that the 100- and 110-volt osram lamps have a useful life of 750 hours, but this counts from the time that the lamp is safely fitted into its lamp-holder and current turned on. No doubt, as in the case of gas mantles,

improvements will be effected, and the breakages which now take place before even the lamp gets into its final position will be reduced; but at present breakages in transit are a serious item to be borne in mind when calculating the cost of renewals.

With tantalum lamps we have obtained guarantees of an average life of 750 hours when run in parallel, and of the same life when run two in series, provided (*a*) that the lamps be properly paired to begin with, (*b*) that if one burns out both be replaced, and the partially worn-out one paired up with another partially worn-out one, and (*c*) that the voltage of the lamp corresponds, not with the declared voltage, but with the highest voltage actually obtaining on the circuit in question.

It is common knowledge that even with the drawbacks above referred to, many large business consumers are putting in metallic filament lamps, two in series, and many stations can testify to great reductions occasioned thereby in consumers' accounts. One thing is certain, that if a larger proportion of the total annual outlay on lighting is to be paid to the lamp-makers, the amount coming to the supply station must be considerably reduced if the total is to be reduced or even to remain the same.

If the consumption per consumer be reduced by say one-third, it is not sufficient to increase the number of consumers by 50 per cent., as this only just keeps the output at its former figure, without allowing for increased capital outlay on services, and increased expense in meter reading and general administration. It is, moreover, very doubtful if there are many districts where the number of consumers could be *quickly doubled*, whatever may be the result in the long run.

The foregoing remarks apply to those cases where 100-volt 25- to 30-c.p. lamps are used, two in series, on 200 volts or thereabouts.

In our own private houses we last year tested a plan, which appears likely to become very general where alternating supply is available. This consists in putting down an auto-transformer, or "distributor," by which the 200-volt supply is broken up into eight circuits of 25 volts each, thus permitting the use of 25-volt metallic filament lamps of 8 and 14 British candle-power, which are both cheaper in first cost and more efficient and stronger than the 100-volt lamps. The 8-c.p. 25-volt osram lamp is rated at 10 watts, and the 14-c.p. at 16 watts.

We have carefully studied the behaviour of both lamps and transformers and find them in every way satisfactory.

It may be objected that the transformer losses during the day-time would go far towards neutralising the saving in current during the lighting hours. In our own case we obviated this by keeping carbon filament lamps in bedrooms, and arranging two-way switches on the ground and bedroom floors, by means of which the transformers are switched off last thing at night and not turned on again until the downstair lights are required again. There is now, however, on the market more than one switch which automatically switches the transformer off when the last lamp is turned off and switches it on again when a lamp is turned on.

Under these circumstances we find that the consumption of current for the same illumination is only from one-third to one-half of what it was formerly.

In shops and business premises the provision of a switch to turn off the transformer during the non-lighting hours presents no difficulty.

We have taken tests of transformers made by different makers, each wound for eight circuits of 25 volts, 200 volts across outers, for 4 to 5 amperes per circuit at 50 ∿ per second.

We find that the no-load consumption, all lamps turned off, varies from 12 to 15 watts.

The lamp, unlike the 110-volt one, can be used in any position and fits any ordinary shade, is listed at 3s., and as an electrolier with six 8-c.p. lamps, only consumes the same amount of energy as an ordinary carbon filament 16 c.p. lamp, it is evident that the system presents many advantages.

A well-known London company was last year approached many times by the makers of metallic filament lamps, but refused to make any change, as most of their lighting was by means of 8-c.p. lamps on three- and five-light electroliers, with the lamps at varying angles, and in many cases enclosed in rather small glass flambeaux. They subsequently adopted the 25-volt auto-transformer system, which met all their requirements. A meter was put in circuit with the lights on a portion of the installation, consisting of fifty 8-c.p. lamps (carbon filaments), the meter reading over two hours being 3·25 units. An auto-transformer was then put in the basement below the distribution board, and the lamps changed to 8-c.p. 25-volt osrams, when the meter reading over the same length of time was only 1·10 units.

Since then these transformers have been made in large quantities, and it is quite evident that as soon as they become general, the accounts of consumers on alternating-current systems will be considerably reduced.

Continuous-current stations are not affected in the same way, but who can doubt that before long the price of metallic filament lamps will be largely reduced, and a satisfactory 200-volt lamp put on the market? Indeed, we are already promised within the next few weeks a 50-watt 40-c.p. 200-volt lamp.*

Both these events would largely increase the number of users of high-efficiency lamps and lead to a general reduction in lighting accounts. This will not affect so seriously the large companies in the manufacturing centres which have a large power load and are able to supply lighting current at very low rates, but it will, we think, until prices are readjusted, prove most serious for the large number of stations in residential districts dependent almost entirely on a lighting load.

What steps are the supply stations going to take to meet this? For some time to come it is hopeless to expect that the number of new

* The progress of events is so rapid that even since this paper was written the prices of some makes of lamps have been reduced; new lamps have been put on the market and improvements made, all tending to popularise high-efficiency lamps.

the case of electrical energy, by far the greater part of the charge is due to standing charges, interest, and sinking fund, which are independent of the amount used by the consumer, the actual cost of production of the current being relatively small.

In this respect electrical supply resembles much more closely water supply, where the actual water costs little and all the expense is incurred in being in a position to supply, rather than gas supply, where the actual costs of production are high as compared with the standing charges. It follows from this that if any individual consumer reduces his consumption by one-half, the reduction in the amount of profit to the supply company is much greater in the case of electricity than it is with gas.

Suppose that a gas and an electrical company each lose 20 per cent. of their business. From the figures above given, the profit in the case of the first is £25, and in the second £53·145 per £100 gross receipts.

Even assuming, therefore, that the working costs were in each case reduced *pro rata* with diminished output, which is not the case, the former loses £5 and the latter £10 15s. of their profit, and in order to keep their dividends the same it would be necessary for the gas company to raise its price by 6·25 per cent., whilst the electrical company, to be in the same position, must increase its rate by no less than 13·4 per cent.

Many gas engineers are of opinion that it was the introduction of slot meters and the large accession of small consumers consequent thereon which, together with the increase in gas cooking and heating, saved the gas companies when the gas mantle was introduced. With their low capital charges and low service costs they can profitably supply small consumers; indeed, the average revenue per gas consumer throughout the country works out from the Board of Trade returns at £5 8s. In the case of one district only which we investigated recently, we found that a gas company was in possession, and paying, to the satisfaction of its shareholders, the full statutory dividend of 10 per cent. From the figures supplied to us it appeared that a large proportion of the consumers had about six lights in use, and their bills, including meter rents, did not average more than £1 16s. per annum.

We came to the conclusion that such consumers were not likely to furnish a very satisfactory load for an electricity undertaking. Some form of so-called "free wiring" would be absolutely necessary in order to supplant gas, as the interest on this, with the cost of meter and service, would come to some 12s. to 15s. per annum before any current could be supplied at all.

We should like to hear the experience of other engineers in the matter of small consumers. We have made many attempts to solve the problem of economically and profitably supplying them, but we have to confess that, speaking broadly, we have not found this class of consumer remunerative.

When we came to reckon up the cost of "free wiring" repairs, renewals, cost of slot meters, services, etc., we were forced to the con-

clusion that under ordinary circumstances such consumers do not pay.

The new lamps reduce the old 20-light consumer, who could be profitably supplied, to about the same as a former 8- to 10-light consumer; in other words, they reduce the demand of a profitable consumer to an unremunerative amount, so that the difficulty of finding fresh consumers likely to pay the station is increased just at the moment when they are most urgently needed.

In the case of the installation referred to on page 335, they formerly had 686 8-c.p. lamps, consuming 36,260 units per annum, at an average price of 3.47d. per unit—a fairly low rate. This made their annual account—

	£	s.	d.
Total cost of current per annum	524	0	0
Lamp renewals (1,612 lamps at 1s.)	80	12	0
Total	£604	12	0

The 25-volt osram lamps have now been adopted throughout, but unfortunately a sufficient time has not elapsed to allow the exact saving to be ascertained. The present costs for slightly better illumination than before, at the same charge per unit, would be approximately—

	£	s.	d.
12,500 units at 3·47d. per unit	180	14	7
Lamp renewals (1,612 lamps at 3s.)	241	16	0
Total	£422	10	7

It will be seen that whilst the lamp-maker now receives £241 16s. instead of £80 12s., the supply station only sells 12,500 where it formerly sold 36,260, or, in other words, it has lost 65 per cent. of its business, and in order to keep its profit the same, would, on the average figures given a few paragraphs above, need almost exactly to double its charge for current, or, in other words, charge 6·94d. per unit.

In practice, of course, the result would be different, as owing to new consumers coming on and old consumers raising their standard of illumination, such a reduction in the total output as 65 per cent. is not likely to obtain, and an increase in the price of from 10 per cent. to 15 per cent., depending on circumstances, would probably put the station in a favourable position again.

Fortunately for the supply company, the installation above cited is supplied on a sliding scale depending solely on the quantity consumed, and as a matter of fact their bill will be—

	£	s.	d.
10,000 units at 4d. per unit	166	13	0
2,500 units at 3¼d. per unit	36	9	0
	£205	2	0
Lamp renewals (1,612 lamps at 3s.)	241	16	0
Total	£446	18	0

or an average price of $\frac{£205 \times 240}{12,500} = 3{\cdot}93$d. per unit.

Had they been charged on the maximum demand system, the price per unit would have remained at 3·47d., as the total maximum demand has been reduced in the same proportion as the total consumption.

If the consumer is to save money, and the lamp-maker to get a higher price for his lamps, is it unfair to ask that the supply station should get a higher price for its current, or, at any rate, that the present downward tendency in the price charged should be checked?

It appears to us that the time is opportune for a further consideration of the method of charging in the case of those electricity supply companies a large proportion of whose current is sold for lighting purposes, to see whether by any rearrangement it is possible, without raising the price to the average profitable consumer, to make those contribute their fair proportion who at present do not do so, and also to encourage the use of current for various purposes beside lighting, thereby extending the hours over which the station's large capital expenditure is earning interest.

It is probable that nobody has done more to advance the electrical industry than Mr. Arthur Wright by his masterly exposition of the principles underlying the costs of electric supply. All interested in these matters are naturally familar with Mr. Wright's papers on the subject, more especially the one read by him before the Institution in 1901.

The situation created by the introduction of metallic filaments only serves to lend additional force to the principles he then enunciated. Unfortunately, however, the public have not always realised the advantages that the use of the maximum demand indicator confers.

In many cases stations which formerly charged on the maximum demand system have now reverted to, or offer as an alternative, the flat rate, not because the latter is a fair and equitable system, but because of the trouble in getting consumers to understand the theoretically more perfect one. In addition a lower rate is granted for current required for heating or power.

The inherent difficulty of the present arrangement of differentiating between the charges for lighting and heating can best be shown by an example. A dining-room has an electric hot plate, for instance, supplied with current from a plug near the fireplace. The plug is wired on a separate heater circuit, and above the plug is a small red lamp which serves as an indicator to tell whether the current is switched on to the hot plate or not. This current is probably charged at 2d. per unit, and is often being used at dinner-time, that is to say, on the peak of the station load.

At the side of the plug is another one supplying current to two standard lamps on the mantelshelf, the current for which, being used for general lighting (and not for red lamps), is charged at 5½d. per unit. Can anything be more illogical?

Why should current, consumed during peak times, be charged at low rates simply because it is not used for lighting? It cannot even be contended that the hot plate in question is a long-hour consumer.

Attempts to carry out such a system of charging have been made in many districts, perhaps the best known one being that introduced into Manchester by the late Dr. John Hopkinson, in which the price charged depended on a fixed rental plus a proportional charge for energy. The fixed rental was determined by the number of 8-c.p. lamps, or the equivalent thereof, wired. In Manchester the system has now been abandoned, partly, we believe, because the tendency was to keep down the number of lights per house to a minimum.

A variation of this is the system which was adopted at Hastings by Mr. Andrews, and also by Mr. Ruthven Murray, of the North Metropolitan Power Company, and others. In these cases the fixed rental is based not on the number of lamps wired, but on the maximum number in use in any quarter as shown on a maximum demand indicator.

At Hastings the charge was 10s. per annum for each 8-c.p. lamp of maximum demand, and in addition 1½d. for each unit consumed, as shown on the ordinary meter. As an alternative, consumers could pay a flat rate of 6d. per unit, and in addition there was a special rate for power.

It will be noted that nearly every station has to give flat rates as an alternative, and also special rates for power. Indeed, many large stations, having abandoned the use of demand indicators and the maximum demand system of charging, get over the difficulty in a rough-and-ready sort of way by quoting each consumer a special flat rate depending on what they consider is likely to be the nature of his demand. The difficulty here is, of course, in making one consumer who is charged, say, 5d. per unit, understand why he should pay more than his neighbour, who perhaps has a smaller consumption, but is only charged 2d. per unit. This may work in a large London district where no one knows his neighbour, but it would be unworkable in a country town.

Section 31 of the Clauses Act further provides that in the event of the undertakers charging by any special method approved by the Board of Trade, any consumer has the right by giving one month's notice in writing to require the undertakers to charge him by the actual amount of energy supplied to him.

The result of this is, of course, that if it pays a man to take a supply on any special system, he accepts it, whilst those at the other end of the scale who are unprofitable at a flat rate, but would be forced to pay more on a special system, naturally elect to pay a flat rate, so that any special system at a point where it would become advantageous to the company is defeated by the provisions of the Electric Lighting Acts. In addition, many engineers will make various concessions to a consumer who threatens to give up using electricity, quite overlooking the fact that it may be much more profitable to let a very short-hour unremunerative consumer go, and to replace him with a more profitable one, rather than spend more money, worth with sinking fund 7 per cent. or 8 per cent., on mains and plant to keep him on the circuit.

Owing to the conditions that pertain, electricity when in competition with gas, should be able to show a considerable advantage to long-hour consumers, while gas, on the other hand, should be able to supply very short-hour consumers at a profit where an electric supply company would possibly make a loss.

If electrical undertakings are to be helped at the present juncture by the extended use of current for power, cooking, and similar uses, in the same way that the gas stove and cooker came to the rescue of the gas companies, it is essential that the whole of the business be simplified. It must not be necessary to put in a separate meter, separate wiring, and to render two separate accounts, but, nevertheless, it is equally essential that current for power should not be sold for a low rate simply because it is for power, and the loss made good by lighting consumers.

The great majority of domestic heating appliances take a current of under 5 amperes, and it should be possible to attach any such piece of apparatus to any convenient plug on the general house wiring. The ordinary householder will not buy an electric kettle—he will not even use it if given to him free—if he has to pull the house about to put in special wiring and to pay 3s. per quarter for the rent of a second meter. Electric-heating appliances could be put on the market much more cheaply than at present if the demand were greater, but there is little inducement to the makers to cheapen them under existing conditions.

It appears to us that the above difficulties might be met if the present minimum charge authorised by the Board of Trade were made to depend on the maximum power with which any consumer should be entitled to be supplied.

Section 28 of the Clauses Act of 1899 entitles the consumer to a supply up to the maximum that may reasonably be anticipated on his premises, and why his standing charge should not be based on the number of kilowatts corresponding to that maximum instead of on an arbitrary 20 units, it is difficult to see.

If a suitable *maximum* figure per kilowatt were fixed by the Board of Trade for that purpose, the actual figure charged by the station could be made to correspond to the standing charges of that station, when it is clear that the charge per unit would resolve itself into production costs and nothing more.

We venture to make the following suggestions for working out the system in practice :—

A consumer applying for a service states as at present the number and candle-power of lamps he proposes to use, say for example, 200 8-c.p. lamps. From his knowledge of the district the station manager estimates that the maximum demand he is ever likely to make on the station is, say, 3 k.w., which he accordingly enters as his "contract demand."

(We use the term "contract demand" for the "maximum power" referred to in Section 28 of the Clauses Act, for want of a better word, to distinguish it on the one hand from the maximum demand as given

during any quarter on a demand indicator, and on the other from the maximum possible demand corresponding to all lights being on at once. In practice the sum of the consumer's "contract demands" will be somewhat greater than the sum of their maximum demands as shown on their demand indicators for the heaviest quarter, but considerably less than the total of their maximum possible demands.)

For the privilege of having the call at any time on power up to 3 k.w. the consumer will pay per annum a fixed sum, and in addition a small charge per unit for the actual energy supplied as measured on the ordinary meter. The fixed charge represents the cost the station is put to in placing at his disposal a supply up to 3 k.w., and is independent of whether he actually uses a unit or not. It is arrived at by dividing the sum representing the whole of the "preparation costs," that is, all those which are independent of the actual output of the station, including, in the case of companies, a reasonable dividend, by the sum of the consumer's "contract demands." The charge per unit is intended to represent the "production cost" per unit consumed with a reasonable margin of profit.

The following examples will show how the charges would work out :—

A certain alternating-current station, for instance, has a maximum load of 713 k.w. on the station feeders, and the sum of the consumers' "contract demands" would probably be found to be about 990 k.w., depending on the nature of the load supplied.

	£
The interest and sinking fund charges absorbed	6,203
The rest of the "preparation costs" amounted to	4,449
Giving a total of	£10,652

This divided by 990 = £10 15s.* as the standing charges per "contract" kilowatt demanded. The "production costs" per unit were 0·87d., say 0·95 pence, allowing a margin for profit.

The charges would therefore be £10 15s. per "contract" kilowatt demanded, and 0·95d. per unit consumed.

As an illustration take two typical houses, A and B :—

"A" has an equivalent of 60 lamps of 8 c.p., and consumes 655 units at 5½d. per unit, the present flat rate, = £15.

The "contract demand" would probably be fixed at 0·9 k.w., and the charges under the new system would therefore be—

	£	s.	d.
0·9 k.w. at £10 15s. per kilowatt	9	13	6
655 units at 0·95d. per unit	2	11	10
Total	£12	5	4

= 4·5d. per unit.

"B" has an equivalent of 55 lamps of 8 c.p., and consumes 350 units at 5½d. per unit, the present flat rate, = £8.

* By taking 990 k.w. instead of 713 k.w., the maximum load on the station feeders, the consumer gets due allowance for the Diversity Factor.

With the "contract demand" fixed at 0·9 k.w. the charge would be—

	£	s.	d.
0·9 k.w. at £10 15s. per kilowatt...	9	13	6
350 units at 0·95d. per unit	1	7	8
Total	£11	1	2

= 7·58d. per unit.

The tramways take 360,000 units per annum.

Assuming 100-k.w. "contract demand" the charges would be—

	£	s.	d.
100 k.w. at £10 15s. per kilowatt	1,075	0	0
360,000 units at 0·95d. per unit	1,425	0	0
Total	£2,500	0	0

= 1·67d. per unit.

Take next a shop as an example :—

Lamps installed, say, 20 of 40 watts each, consuming, say, 400 units per annum.

"Contract demand," say, 0·8 k.w.

The charge would be—

	£	s.	d.
0·8 "contract demand" at £10 15s. per kilowatt	8	12	0
400 units at 0·95d. per unit	1	11	8
Total	£10	3	8

= 6·11d. per unit.

As applied to a motor load, take, for example, a 10-H.P. motor giving a variable load for, say, 50 hours per week.

The charge would here be as follows :—

	£	s.	d.
"Contract demand," say, 10 k.w. at £10 15s. per kilowatt...	107	10	0
Say 13,500 units per annum at 0·95d. per unit	53	8	9
Total	£160	18	9

= 2·86d. per unit.

This consumer cannot be profitably charged at a lower figure, even on a flat rate, as he has the privilege of coming on at peak load.

If, however, the consumer would agree not to work his motor during lighting hours, or, at all events, during the period covering peak load, *but not otherwise,* his rate per "contract kilowatt" demanded should be fixed as a matter of equity at, say, £5 per kilowatt.

His account would then become—

	£	s.	d.
"Contract demand," 10 k.w. at £5 per kilowatt	50	0	0
13,500 units at 0·95d. per unit	53	8	9
Total	£103	8	9

which represents 1·84d. per unit instead of 2·86d.

The question will naturally be asked, How does the station know that any consumer will not exceed the demand he has contracted for?

One might reply that when some companies quote, as they do now, a different flat rate for different consumers based on what they estimate their load factor is likely to be, they back their judgment and take the risk. Although this is now done every day and appears to work to the satisfaction of the companies employing this method, we do not consider it one to be recommended. It would be preferable, therefore, to insert in every house a "limit indicator," the function of which is to throw a resistance into the circuit, and thus indicate to the consumer by a reduction in the brilliancy of his lamps when he is exceeding his contract limit.

If the consumer thinks that his demand is not so high as the station engineer suggests, the latter will set the instrument to a lower limit, when the contract charge will be correspondingly reduced. In the event of the consumer having under-estimated his contract demand, he will soon ask for his limit to be increased, when his account will automatically increase in the same way.

The point in which this method differs from the Wright system is that the consumer can determine his own maximum, and unless he asks for his limit to be raised, he knows within a little just exactly what his bill for current is to be. He cannot, as with the maximum demand system, inadvertently switch on a number of lights for an hour or so with the result that he finds that he has a much higher bill than the previous quarter when he used the same number of units. That he had under these circumstances to pay a higher bill might be quite just, but it is precisely because the average consumer could not be got to see this, that the system, admirable as it is, has been given up in many districts.

On the new plan if he exceeds his demand he knows it, and has either to reduce it or to apply to the station to have his limit indicator set higher, thereby acknowledging that his requirements are greater and therefore should be paid for accordingly.

It appears to us that the method is one which appeals to all consumers, and its advantages to the stations are obvious. All pay their fair proportion, whether short- or long-hour consumers, whether the current be used in the small lamp for lighting or the large lamp for heating, the desirable long-hour consumer is encouraged, and those with a very bad load factor either pay their proportion or go off the main to make room for more profitable consumers.

There is every inducement to use radiators and cooking apparatus.

When an electric kettle can be bought as an ordinary article, taken home and plugged into any of the ordinary plug sockets, the demand will be such that the price will quickly come down and their use increase at compound interest rate, for as long as they are used in such a way as not to increase the load beyond the contract limit, the only charge will be the small one for so much additional current, in the case of the station above referred to, for instance, 0·95d. per unit. The contract rental will, of course, be regulated to suit the prevailing condi-

tions, and include the ordinary meter rental, which will disappear. Special circuits and meters for heaters and motors will also be no longer necessary.

If still more economical lamps are introduced, thus reducing the aggregate of consumers' contract demands, the contract rental per kilowatt will be raised. If the gradual expansion of the station reduces the cost per kilowatt of contract demand, the rental per kilowatt will be reduced.

It may be objected that in some of the examples given above the charge for current for motors appears high. The answer is, that if motors have the right to come on the mains at any time, the current consumed by them must be paid for at the same rate as the current for lighting under the same conditions; it is only when the motor current does not increase the peak load that it should be charged at a lower rate.

It is an undoubted fact that many stations are now penalising their lighting consumers to supply current for power and heating at low rates, and if the demand for such power increases, the price as compared with the price for lighting current would have to be raised.

It is not as though it were true, as is sometimes assumed for the purpose of fixing charges, that energy for power purposes is used in daylight only and lighting current after dark. The two overlap, and it is just as reasonable to let the lighting consumer have current at a low rate because he uses the machinery at night, when it would otherwise be doing nothing, as the day load is shut down, as to let power consumers have power current at a price which only covers the works cost.

If, on the other hand, in a special case a power consumer were to undertake to use his motors only between certain hours, he would thereby enable the station, for the same capital expenditure, to supply a larger aggregate of demand, thus reducing the price per kilowatt of contract demand. He would then be entitled to charge at a lower contract rental per kilowatt.

Although in our opinion the use of a limit indicator is the best method of working the system, it is obvious that it can be dispensed with, and the contract rental arbitrarily fixed by the station, as is now being done in the case of varying flat rates, or an ordinary maximum demand indicator can be installed and the consumer informed that the contract rental will be so much, provided that the indicator does not show that the assumed contract demand has been exceeded at any period during the whole year. This latter arrangement, although at first sight similar, differs fundamentally from Mr. Andrews' and Mr. Ruthven Murray's systems in that the rental is not dependent on the demand as shown on the maximum demand indicator, but is the same each quarter of the year, this instrument being merely introduced to show whether the agreed contract demand has been exceeded. It is, however, open to the same objection referred to above, namely, that the limit may be exceeded and the contract rental thus increased without the consumer, who cannot be expected to watch his demand indicator all day, being any the wiser.

The present paper does not pretend to put foward any new facts or investigations, nor do we suggest that the subject matter is novel; our object is to endeavour to focus the present position, to bring out clearly, among other things, the new factors introduced into the electrical industry by the advent of high-efficiency lamps, to show the possibilities of a heating load in a residential district, given a suitable method of charging, and to induce a thorough discussion of the subject generally, as we believe that the time has arrived when much is to be gained by a general exchange of views on the subject.

The original method of charging for electrical energy was based on a false analogy with gas. During the quarter century that has elapsed since it was formulated, the conditions have completely changed, and the advent of the new lamp renders it absolutely necessary that the whole question should be reconsidered.

If as a result of the discussion the Institution comes to the conclusion that a change is desirable, there is no doubt that the Board of Trade would be found ready, as it always is, to bring about such alterations as it may consider in the best interests of all parties concerned.

ADDENDUM.

The following particulars of an interesting system adopted by Mr. F. W. Long, City Electrical Engineer of Norwich, may be of interest.

Private consumers in Norwich have the option of taking a supply either at a flat rate of 4½d. or on an "assessment tariff." This tariff consists of a fixed charge of 12 per cent. upon the nett assessment of the house and 1d. per unit for all current used. The system possess many of the practical advantages of the one suggested in the paper, in that it encourages the long-hour consumer, and also the use of radiators, kettles, &c., without requiring a separate meter. Mr. Long informs us that "the result has been that people have used considerably more current and that radiators are becoming popular." He is quite satisfied with the working.

Only a few weeks have elapsed since this paper was written, but much has happened meantime. Two metallic filament lamps are now being sold for one carbon filament lamp, and many matters that were then surmise can now be tested by actual results, and a fairly close answer given to many of the points raised. These results entirely confirm our views as regards the individual consumer, and they also demonstrate that the effect of metallic filament is so complex that generalisation is impossible.

On no two stations are the effects the same; in some cases the first quarter of this year has been better than ever; in others, the normal rate of increase has not been maintained; while others again report a lower peak load than in 1907. From the very fact that the "light supplying capacity" of stations has been doubled or trebled at a stroke, the demand for new plant will be small until matters have re-adjusted

themselves. As against this, the lamp makers will reap a well-earned harvest of their labours, and installation contractors will share their prosperity. For the investor in electric-light undertakings, there is the re-assurance that any dislocation can only be of a purely temporary nature, as even if the consumer, who now pays 5d. per unit, for instance, were called upon to pay double that amount, his electric light would even then cost him less than it did with carbon filaments. This is a fact we must always keep before us.

Provided that the situation is properly dealt with, as it doubtless will be, it is a fact that leaves room for no fear as to the future, for, after all, electric-light stations must be judged, not by "units sold," but by "dividends paid."

Discussion in London.

Mr. Wright.

Mr. A. Wright: I am very glad to have the opportunity of expressing the thanks of probably all central station men to the authors for bringing this very important subject forward for discussion, because I believe we all realise the serious position we are in unless we handle the metallic filament proposition carefully. In my opinion the answer to the question, How will it affect the central station undertakings in this country? entirely depends on the men and how the proposition is managed. If it is left entirely to the wiring contractor, I think that for the next two or three years we shall have quite a bad time, as they obviously have no interest in keeping up revenues; but if the central station men take it up, and insist on people having more light for the same current instead of a less bill for the same light, it is quite possible that we may counteract the revenue reducing properties of the metallic filament. It is quite possible to do this by judicious advertising. For instance, we have immediately to counteract the effect of the advertisements we see every day: "Get the same light with 70 per cent. reduction on your bill." We ought in reply to say, "Get three times as much light for the same bill"; and unless we do that, I do not think we shall, speaking from very considerable experience, counteract the effect of the present attractive advertisement. There is one other point I want to discuss in relation to the gas question mentioned by the authors, and that is, we must remember the great advantage gas companies have over electric light companies, in the way of having no restrictions, or by-laws, or fire rules, either Government or self-inflicted. I think we have done our industry a very great deal of harm in being too ready to try to make the service absurdly safe. We ought at once to follow the lines of the gas companies and trade in their broad manner, leaving the fire insurance offices to look after those risks.

Again, with regard to the economic effect of the metallic filament lamps, we must not overlook the enormous increase of field for business that this new discovery presents to us. It brings into our field a type of consumer that I think many of us have considered beyond the range of

commercial politics. The increased market is so much larger now that I do not feel the metallic filament lamp will do any harm to the electric supply undertaking, and possibly the consumption of current will be vastly increased. There is one effect that I think has not been perhaps sufficiently emphasised in this paper, the enormous reducing power on costs of an increased output from a station. Most of our power stations can supply an extra quantity of electrical energy at a very much lower cost than the average cost they are now supplying at; in other words, the increment cost of extending our business is nothing like the present average cost. I would like to take one case with which I am familiar which probably represents to an extreme degree many other undertakings in this country. Take Marylebone, for instance, where the average cost is 4½d. We can double our output there by an increase of 8 per cent. on our capital, and if we double our output, our average cost would go down to 2½d. So that it is obvious we must do everything in a case like that to increase the output, and nothing in the way of restricting or making the business more difficult to obtain must be entertained. The other point I wanted to mention was this question of why most of us feel justified in charging less for power supply than lighting, although both may occur at the peak time. It is really because of the greater diversity factor of motors compared with lamps. A 1,000 k.w. of load at the station can handle many more kilowatts of motors at the peak than it can of lights, because a motor's load is not necessarily continuous at peak or any other time. In the East End of London, I believe, Mr. Tapper has found that the diversity factor among motors is something like 4, whereas in a purely lighting business it is certainly never more than 1¼. Motors are rarely constantly fully loaded like lamps are. There is one disadvantage which handicaps us as compared with the gas industry, and that is the high cost of connection to the consumers. At present it nearly costs as much per kilowatt to connect a house as it costs to build a power station; and while we are taking all the trouble to reduce the cost of the power station capital, nothing up to now has been done to reduce the equally important cost of house connection. I hope some day we shall be able to have one service per block, and some means of either overhead supply to the different tenements or outside wall conductors, in fact, anything to avoid this £9 or £10 per service, which is so fatal to the supply of current to small consumers.

Mr. Wright.

Mr. H. Hirst: My mind is very full at present of this subject, and I have listened with great interest to the figures and statements which the authors have put before us this evening. They have made me feel somewhat uncomfortable. I do not wish just now to go into the characteristics of the osram lamp, as perhaps might have been expected from me; but I wish really to refer to a few points which have been mentioned in the paper. The authors also give some figures as regards the life of the tungsten lamp. The life of the tungsten lamp in practical experience surprises all makers of carbon lamps, being considerably longer than the life of carbon lamps. The

Mr. Hirst.

Mr. Hirst. statements which are made about series running in connection with tungsten lamps do not apply to-day. The authors mention the conditions under which series lamps are running, although it is true they refer to tantalum lamps. But better arrangements have been provided for running osram lamps in series. It is not left to the consumer to pair them as he likes. The lamps are paired and marked accordingly in the factory. The variation in current consumption during the life of the osram lamp is so small, and the pairing so accurate, that if one lamp out of two burning in series should fail it can be replaced by one of equal series number without necessitating to throw away both as has been suggested. One may put a new lamp in series with the old lamp and they will both run perfectly well. At one period there was a little trouble about this, due to a mistake in a factory, which has been entirely overcome since. Without wishing to go into details, I notice an apparent grievance on the part of the authors that the lamp maker is making too much money out of the metal filament lamp. I think the metal filament lamp is such a tremendous asset to the electric-light industry that it ought to be welcomed by everybody. It is the lamp makers who lose most at the beginning. In the first place, they have to allow heavy depreciation for their existing carbon filament lamp works; they have had considerable expense in connection with patents, or in buying experience, as the case may be, and it will take many years of good prices before their risks are covered. I therefore think that as the station engineers are the ones who will ultimately benefit most by it, the least they can do is to contribute somewhat to that capital expenditure which is wanted for the benefit of the whole electrical industry, and to my mind their capital expenditure consists in the momentarily reduced takings which may be received in some stations. From the figures the authors have given us, it will be seen that we are only taking six millions per year for electric lighting in this country, against twenty-seven millions taken by the gas companies. There is, therefore, plenty of room for fighting the gas companies. As a side issue not without interest, I would like to use this occasion to make public an effort of mine in that connection. When I felt, some twelve months ago, that I was likely, on behalf of the companies with which I am connected, to control these metal filament lamps I had the idea of asking fifteen central station engineers in London whether it would not be a good thing if they were to take up the supply of metal filament lamps to the contractors, for the contractors under their instructions to introduce them, and to direct the policy to such an extent that the metal filament lamps would be used for the first few years, when the supply is rather limited, for absolutely fighting gas rather than to let it go into the ordinary electric-light installations. I thought it was a good idea; the station engineers thought it was an idea for my own benefit, and it fell to the ground. I think if it had been taken up seriously by one set of engineers I should have been encouraged to approach others, and it would have

been a very wise thing in the common interests. It has not been appreciated, and we have, in consequence, certain troubles. Mr. Hirst.

Mr. C. BOTTOMLEY SMITH: Without detracting from the excellent system of contract demands which the authors propose to put forward, from experience I think it would be very unpopular from the consumer's point of view. I have had considerable experience of the minimum charge, and having done away with the minimum charge, and having found the benefit of doing away with it, I think the imposition of a contract demand on consumers, which is practically an increased minimum charge, would have a very detrimental effect on the industry. I can hardly agree with Mr. Arthur Wright's figure of £10 per house service; I think it could probably be done for much less than that. But, without doubt, the question of the house service is the serious question that will affect us, if we look to doubling or trebling the number of consumers so as to make up for the probable loss in revenue owing to the adoption of metallic filament lamps by the consumers already connected. With regard to the system at Hastings of charging 10s. per lamp per annum plus 1½d. per unit, it would appear that as most undertakers are only empowered to make a minimum charge of 13s. 4d. per quarter, equivalent to 20 units at 8d., there might be a difficulty in enforcing this charge in cases where the actual consumption does not reach the number of units at 8d., equivalent to the assessed amount. Mr. Bottomley Smith.

Mr. W. R. RAWLINGS: It is not often that a paper is read before this Institution which induces a large number of contractors to be present. Probably Mr. Arthur Wright was of the same opinion, and overlooked the fact, or he would perhaps have modified some of the statements which he has made this evening. From the contractor's point of view, I think, if there is one thing more than another which has puzzled and upset the average consumer it is the Wright indicator. I once fitted an installation which consisted of about 100 lamps, and it mattered not what the consumer did, he always had to pay 7d. a unit. Another installation which had about 50 lamps was fitted by another contractor, and that consumer managed to get through at 4½d. a unit. There are many systems in existence for charging for electricity. In addition to the Wright system, there is one used in Kensington which was introduced by Mr. Erskine, of the Kensington and Knightsbridge Company, and while the principle is a good one the consumer has a great deal of difficulty in understanding it. He understands it at the end of his first financial year, which is a little late to get new consumers, and therefore the system suffers somewhat from the point of view of extending business. The Wright system, the Erskine system, and others now in use do not in my opinion bring about that which is necessary, namely, the economical use of the energy and of the wires which are installed in the houses. There are a number of installations in Kensington where there are no less than three meters, three main switches, three double-pole fuses, and three sets of fuse-boards; while one set of meters, switches, and fuse-boards would be Mr. Rawlings.

Mr. Rawlings.

sufficient to meet the whole of the requirements. The triplicating of the wires and apparatus is brought about by the present absurd system of charging. The consumer may use the energy at any time, as the authors have pointed out, but it is this multiplication of wires and apparatus which checks the development of the industry. We have from time to time consumers asking us for an electric kettle or a food-warmer, for example, but when told they will have to pay 4½d. or 5d. a unit for the energy unless they have a meter and a set of wires put in for it they give up the idea of using such apparatus, and consequently the manufacturers, suppliers of energy, and the contractors suffer. The authors' system encourages the use of small apparatus, and I think meets the requirements of user and producer. I have collected some figures which will, I think, go to prove that the system proposed by them stands on a good financial basis. I took the readings of 24 meters of different consumers in Kensington, whose requirements I know personally, and therefore I am fairly well able to judge what their maximum demand in kilowatts is likely to be. A boarding house which has 49 lamps installed consumes 33 units per 8-c.p. lamp annually. This, it will be admitted, is a good consumer from the station point of view. As it is a large house with a small number of lamps installed two-thirds of the lamps installed would be a fair maximum demand. Taking this as the "contract demand" at £15 per kilowatt and 1d. per unit for the electricity consumed, I found that the bill would have amounted to 426 shillings for the year as against 694 shillings, which the consumer is now paying, showing a saving of 268 shillings for the year. Then I took another consumer, who is a bad consumer from the lighting station point of view, namely, 8 units per 8-c.p. lamp, with 176 lamps installed. In the house there is a lamp in every hole and corner —a very good customer for the contractor, but a bad one for the supply company. In this case I estimated that one-third of the lamps installed would well cover all requirements, and calculating this on the same basis as before, namely, £15 per kilowatt demanded and 1d. per unit, the charge would have been 715 shillings for the year, whereas at the present time he pays 634 shillings, or an increase of 81 shillings. In my opinion these two cases prove the soundness of the authors' proposals. I have a very large number of figures from which I could quote, but I may say that the average of the 24 consumers is 15 units per 8-c.p. lamp, and if two-thirds is taken as the "contract demand" the average cost would be 384 shillings as against 353 shillings at 5¼d. per unit. There is one point which I think the authors have overlooked in their paper, and that is making provision for special illumination, say, for parties and similar events. It is common practice in the West End of London to have annual parties, or sometimes two or three parties a year, when the contractors are often called upon, not only to turn on every lamp in the house, but also to put in lights, perhaps, for a temporary ballroom, thus increasing the load over 100 per cent. above the usual requirement. It therefore seems to me that to make the scheme complete they should have some method of charging a fee to cut out the demand indicator.

Mr. F. M. LONG (Norwich): There is no doubt that the authors have brought before us a most interesting subject, and as they have referred at the end of the paper to Norwich, it would be of interest perhaps if I gave a few particulars about the system adopted in that city. About eighteen months ago I had to consider the question. We were prepared then to make a certain amount of reduction to consumers, but not to the extent of ½d. a unit. I wanted at the same time to encourage those consumers who were profitable to us and also to encourage the use of radiators and heating appliances in the private houses. It occurred to me then that if we could fix the standing costs in some definite way—perhaps on the assessment of the house—it would have many advantages. I went into the matter, and took a number of consumers' houses, and put the consumptions for a year against the rateable values. At first sight there appeared to be very little connection between the two: some large houses used a small number of units only and some small houses a comparatively large number. I then grouped these houses according to the rateable value; for instance, houses up to £15 were put together, and those from £15 to £20, from £20 to £30, and so on. I took the aggregate units for each group and divided by the aggregate of the rateable values, and I found I got just the same figure for each group; that is to say, I found that, on the average, the consumption came to about 7 units per £ of the assessment, for small as well as for large houses. This showed that the rateable value was on the average a measure of the consumption, and since the load in all private houses is of a very similar nature, it follows that the rateable value is also a measure of the average maximum demand of a house, and can therefore be used as a basis for determining the amount of the standing charges that each house should pay. I found that if we were to charge 10 per cent. on the rateable value and 1d. per unit we should get the same income as before. Inasmuch, though, as some consumers would not gain any advantage by this system, and would therefore remain on the flat rate, I thought it was better to put it a little higher, and we fixed the amount at 12 per cent. on the assessment and 1d. per unit. The system was started at the beginning of 1907, so that we have had fifteen months' experience of it. The advantages are, as stated in the paper, that only one system of wires is necessary throughout the house. There are no meter rents, and the consumer knows within a very small amount what his bill is likely to be per year, consequently there is very much less dissatisfaction. About 400 consumers started on this system, but the number is now about 800. At the end of twelve months I made a comparison; there were about 250 that had been on the whole of the previous year with whom a fair comparison could be made. I found that these 250 consumers increased their consumption 20 per cent.; at the same time the amount of revenue received from them was reduced by £328, that is a 20 per cent. reduction; they brought in 3·1d. per unit instead of 4·5d. before. I should point out, however, that those who came in first were the

Mr. Long.

Mr. Long. ones that would get the most advantage out of the system, and the others who have come on since have not obtained so much reduction; in fact, many have very much increased their consumption and are paying more than before. We pointed out to them, that under this system it would be much cheaper for them to wire every room in the house rather than to use gas or candles in some parts. In addition to that we have supplied over 120 radiators, which have a very useful load. They are used mostly, I think, in bedrooms, and I do not think they come very much on the peak. It is rather difficult for me to know how much the maximum load is affected by this system, as there are no demand indicators in the houses. However, I compared the output on Sunday evenings (which is nearly all private house lighting) for December last year with the year before, and I found there was only about 1½ per cent. increase in the maximum load, whereas there has been about 8 per cent. increase in the consumption, so that it looks to me as though we were getting a decidedly better load factor for the private houses than we had before. I do not think the suggestion of contract demand is so suitable for a private house as the basis I have taken of the assessment. What is, I think, more reasonable is to charge on the basis of the normal demand, and this is on the average very well represented—at any rate in Norwich —by a percentage on the rateable value. Business premises have to be treated in a different way; the assessment cannot be taken as a basis for charging, and in such cases I have already in a small way practically adopted the system which has been suggested by the authors, taking the maximum demand of the place and charging at the rate of £10 per kilowatt and 1d. per unit. I found this very useful in a number of cases as a means of giving a reduction to those consumers who are good consumers from our point of view. Under such a system there is the question as to whether the consumer will increase his load after he has settled on it. I do not think limiting arrangements are altogether satisfactory. A better plan, if one can adopt it, is to include the maintenance of the lamps in the charge. One then sends round periodically and it can be ascertained exactly how many lamps a man has in his place. In many cases that gives greater satisfaction, especially with some of the small consumers, where they will not trouble to maintain the lamps properly. They like to have a fixed charge to cover everything, and we find that has worked very well. A fixed charge and 1d. a unit gives one considerable scope. One can charge the £10 per kilowatt for ordinary lighting, but for such things as signs and advertisements generally, which it is desirable to encourage, one can charge rather a lower rate, say £5 a kilowatt, and all the current can go through the same meter. I think it is a very important thing to avoid a great number of meters.

ADJOURNED DISCUSSION, APRIL 23, 1908 (LONDON).

Mr. CHARLES P. SPARKS: Personally I welcome the metallic filament lamp as being the greatest step forward in the supply business that we have seen for the last twenty years. The authors suggest that the coming of this lamp which consumes only one-third the energy per candle-power of the carbon filament lamp is going to be a great handicap to the supply business. They suggest that the gas companies were heavily hit by the introduction of the mantle, and from that draw the inference that we are going to be hit in the same way. I do not agree with that assumption, as the gas companies had possession of a much larger field at the time the mantle was introduced, and in consequence the introduction of the mantle did arrest their progress; the gas consumption did not go back, but it did not advance as quickly as it had been advancing before. In the case of electric lighting many of us have only scratched the ground, and we have a much wider field offered us through the introduction of this metallic filament lamp. Again, I do not agree with the authors with regard to the question of the field. They have put it to us that it will not pay owing to the very high cost of connecting the small consumer. There is an enormous number of moderate-sized consumers that it will pay us to connect, whom we have not yet connected. Further, with regard to the question of the standard of lighting, people pay a certain amount for illumination. In the past they may have been paying, say, £3 or £4 a year, and they will still continue to pay in the vicinity of that figure. It is not necessary for them to cut down their bill for lighting to £1 10s. or £1. On the other hand, if an improvement is introduced which entails increased cost in lighting, it will have a reaction, and a man who is prepared to pay £3 or £4 a year for his lighting will not pay £6. I am hopeful that the metallic filament lamp will mean that the standard of lighting will be again raised. Then as to the different classes of business, I think the metallic filament lamp will have the greatest effect on the private lighting business. Small companies supplying principally private lighting will suffer a certain set-back, but for companies or local authorities supplying large areas with a mixed class of business, public and private, I am sure the metallic filament lamp will mean a general advance and increased prosperity to the industry. One word with regard to the tariff. In the paper the maximum demand system and other tariffs are suggested in order to get over the difficulty we meet with through being unable to store our energy. Mr. Arthur Wright's system has been alluded to in the course of the discussion. I have the greatest possible appreciation of Mr. Wright's methods and papers, and for the way in which he has educated us, but I do feel that we owe him a grudge in the fact that he ever invented the demand indicator. Unfortunately a large number of us used this demand indicator some years ago. Its use has now become almost extinct. The difficulties, not only of the supply company, but of the consumer, when these indicators were used on any large scale, were very great. I think one

Mr. Sparks.

Mr. Sparks. of the principal reasons that business has gone ahead of late years has been the simplification of the tariff. A very ingenious system was suggested during the course of the discussion, which is also mentioned in the paper—namely, that of charging a fixed amount on the rateable value of the property, and a low price per unit for the energy consumed. That is a sort of tariff that can be applied in small towns by local authorities, but a company could not apply such a system. The public are sufficiently worried by existing "rates" for public purposes.

Mr. Stearn. Mr. C. H. STEARN: I fully agree with the authors that the most easy and satisfactory transition from carbon to metallic filament lamps is made on alternating-current circuits by the use of auto-transformers, for in that case we have a lamp, as they have pointed out, mechanically strong, or at least comparatively mechanically strong, and cheaper in price; we can use our small units; in fact, we have to adapt the voltage to the lamp instead of the lamp to the voltage, which is a very much easier matter. But when we come to direct currents or to alternating currents without the use of transformers we have a much more difficult problem before us. Owing to the low specific resistance of all metallic filaments, it is impossible to use them in any other way than in series, whereas with carbon filaments of a high specific resistance parallel lighting is what they are most adapted for. There is no other way of using metallic filaments except in series, and they are equally in series whether we (*a*) collect a number of filaments in one bulb, whether (*b*) we place each filament in a separate glass enclosure, and then collect them on a common base, or whether (*c*) we distribute those small units at a distance from one another connected in series. The disadvantage of the first two methods is that the higher the voltage the larger must be the unit of light that is concentrated in one spot. That is not, of course, the most efficient method of lighting, but if we do this we have a choice of two things: either we must collect all the filaments in one bulb or we must place them in several. It seems to me that if we place each filament in a separate enclosure, and then assemble those filaments on a common base, the maintenance of the lamps becomes much more economical. If they are all collected in one, the higher the voltage the higher is the price of the lamp, and, unfortunately, at the same time the more delicate it becomes. A lamp may cost 5s., 6s., 7s., 8s., or 9s., and five minutes after it is put up it may be ruined by some accident, and therefore a comparatively large sum is lost at once. If each filament is contained in a separate vessel (tubular vessels are the best, as it permits of placing them closer together), which is then placed on a common base, if one is lost it is a small loss. Suppose, for instance, we take a 100-volt lamp, consisting of five 20-volt filaments, and the lamp costs 5s. Suppose, then, that each filament is put in a separate tube, the cost of which is 1s. each, the price would be the same for the perishable part of the lamp. These filaments are exceedingly delicate. It must be remembered that, as compared with carbon, they are on an average about

three times the length and one twenty-fifth of the section for the same candle-power at the same voltage, and if there is the smallest flaw of any description in one filament the whole lamp is lost at once. But if the filaments are isolated, then the average life of the lamp is enormously increased. I should like to give the result of one experiment which I made. I do not mention it as a typical one of the duration of lamps, but it illustrates the point I want to make with regard to the cost. A group of five of these filaments enclosed in separate tubes was combined to form a lamp of 100 volts. At 600 hours one filament broke, and of course that would have meant the loss of the whole lamp under ordinary circumstances. That filament was renewed, and after 2,000 hours a second failed. That was renewed, and at 2,600 hours a third failed. The experiment was not carried farther. At the end of that time we had two filaments that had run the whole time and we had renewed three. Supposing it had cost 5s. originally, that meant that we had spent 8s. for 2,600 hours instead of 5s. for 600 hours. In practice one would probably not get such durations as that as an average, but the experiment illustrates the point sufficiently, that it is much cheaper to enclose the filaments separately instead of collecting them all in one vessel. Mr. Stearn.

Mr. P. STILL: The authors' suggested scheme of charging based on a contract demand is very interesting and ingenious, and I think from the point of view of providing an adequate return on the capital invested in making provision for the supply to each individual consumer, it is satisfactory. The convenience which it may provide in doing away with the necessity of using more than one meter in the case of a consumer who wishes to make use of the supply for different purposes is also, I think, a great point in its favour. In view of this and other advantages, it was, therefore, with very great regret that, on reading through the paper, I came to the conclusion that the system of charging suggested was not practicable. I think it offers at least two very serious difficulties and objections. The arbitrary fixing of the contract demand by the electricity supply manager would be a very difficult matter indeed, and I feel sure it would lead to constant and interminable discussions and difficulties with the consumer. When one sees the application form from a customer, on which the particulars are stated as to the number of lamps and other apparatus for which the supply may be required, it is quite impossible to form any idea as to what the load will be on which the contract demand system should be based. More particularly in the case of private house lighting, whatever knowledge the electricity supply manager may think he has of the district, it is impossible to form an opinion from the number of lamps declared as to what proportion are likely to be generally used. That proportion will depend upon the particular habits of that consumer, upon the manner in which the installation has been wired, and upon whether it has been liberally lamped or sparingly lamped. The candle-power of the lamps, too, is a very uncertain quantity, because frequently 8-c.p. lamps, which are declared in the Mr. Still.

Mr. Still. first place, are subsequently altered to lamps of higher candle-power when necessity arises. With regard to the efficiency of lamps, particularly at the present time, it is a matter of great uncertainty as to whether carbon filament lamps, metallised filaments, tungsten, tantalum, or any other type of lamp may be made use of, and also as to how these may be subsequently changed by the consumer. The uncertain and irregular use of heating and other electrical apparatus is another point which would add to the difficulty of fixing the contract demand. It is true that the authors propose the use of a limit indicator to get over the these difficulties, but I feel sure that any such apparatus would not only be unsatisfactory in its working and expensive to maintain, but that it would also lead to other serious difficulties with the consumer. The second objection which I foresee to this system is that any system of charging based upon a contract demand presupposes a fairly regular annual use of the supply by the customer. This may be workable in the case of shops and certain business premises, but in the case of private house-lighting—certainly in the London residential districts—it would be an impossibility. Private houses in these districts, unfortunately, use the supply in a very irregular manner. Many of these houses also change their ownership fairly often in London, and such consumers would have the greatest objection to agreeing to a system of charging based upon a regular annual use of the supply. In the case of power supplies to factories, of course the matter is a very different one, and a system based upon a charge per kilowatt and a reasonable charge per unit slightly in excess of the cost price may work very well, but for private house lighting I think there is no doubt whatever that what the consumer wants is a flat rate. I should prefer to have various flat rates for various classes of supply, and though the system may not be perfect, it at least has the merit of simplicity and straightforwardness.

Mr. Andrews. Mr. LEONARD ANDREWS: I gather from the remarks of previous speakers that the general opinion is that the authors have taken too pessimistic a view of this question of the possible effect of metallic filament lamps upon certain supply stations. I quite agree that the introduction of the metallic filament lamp is an excellent thing for the entire industry, particularly for lamp makers and wiring contractors, and I believe ultimately for the supply undertakings. But I do think there is something in the danger referred to, and in that connection I would like to draw attention to a note that appeared in one of the electrical papers a few weeks ago. This paper reported that a certain electricity undertaking "anticipates a deficiency of £3,581 for the year ending March 31, 1908. In their Report the Committee state that the reduced income from private lighting is almost entirely due to lower consumption, in consequence of the increased use of metallic filament lamps." Now the gross revenue of this undertaking is less than £20,000 a year, and two years ago they made a profit on fifteen months' working of about £2,200 or £2,300, say, at the rate of about £1,700 for twelve months, so that there has been an annual falling off

in profits of about £5,000, or 25 per cent. of the gross revenue which the committee attribute chiefly to the introduction of the metallic filament lamp. To this must be added the loss of natural growth of business for the two years, which for six consecutive years prior to the introduction of the metallic filament lamp averaged over 18 per cent. per annum. I am inclined to think with the author that, whereas the large reduction of consumers' bills will undoubtedly induce a number of new consumers to come on to the supply mains, the capital charges of connecting on new consumers will absorb such a large slice of the revenue from such sources that it will probably be impossible for the undertaking referred to to regain its position without increasing its charges, though I admit this is a course to be deprecated if it can possibly be avoided. Mr. Andrews.

The question of systems of charging has come in for a good deal of discussion, and it appears to me that the more we discuss the matter, I will not say the further we get from it—but we do not seem to get any nearer to it. It appears to me that even a flat rate may be really very inequitable. We know, for instance, that it is impossible at the present time to sell current to certain classes of consumers at a flat rate of 5d. per unit and cover all charges. On the other hand, we know it is quite possible to sell electricity for use by other classes of consumers at an inclusive rate of ½d. per unit, and to make a big profit. It is difficult to understand how the advocates of a pure flat rate can reconcile these admitted facts. It does seem, therefore, that we ought to get away from the idea that a unit of electricity is a commodity that can be sold at a fixed price without taking into consideration the purpose for which it is to be used.

The authors have asked me to state how the system I introduced some years ago at Hastings, to which they refer in their paper, worked in practice. It was entirely satisfactory where the Wright system had been a complete failure, and I think the reason it worked so well was that every consumer understood it. We found at Hastings that the effect of introducing this extremely simple basis of charging was that the growth of business during the three years following the introduction of the system was greater than it had been in the previous fifteen years, and, what is more, the load factor at the generating station was greatly improved. We found the current was being used intelligently. Quite a number of consumers who had previously used electric lighting in their windows and front shops only had their basements wired. They used the current in their basements in the daytime, and when it became necessary to light the windows, turned the current off in the basements and lit the gas, thereby obtaining all the current for the basements at 1½d. per unit, and materially improving our load factor. There is one incidental advantage that the Hastings system shares with the Norwich system described by Mr. Long at the last meeting, and that is, with intelligent use either system provides a means of dealing with the metallic lamp difficulty since the principal charge is based upon the nominal light given instead of upon the consumption of current.

Mr. Andrews.

If, when it was found that the metallic filament lamp had come to stay, an announcement had been made that to encourage the use of these new lamps the maximum demand charge would be reduced from, say, 10s. to 7s. 6d. per 8-c.p. lamp, or its equivalent to consumers using a reasonable number of metallic filament lamps, and that the flat rate would be increased from 6d. to the statutory rate of 8d., an excellent boom might have been made out of the reduction, and the increase in the flat rate would have hardly been felt, as it would have merely induced more consumers to make application to be charged on the maximum demand basis. I am convinced that if this course had been adopted by the undertaking referred to in my opening remarks, and other causes of loss had been steered clear of, they would have been in the position of being able to record an increased profit instead of a falling off in profits of approximately £5,000 per annum. At the same time the supply undertaking, the lamp makers, the wiring contractors, and the consumers would all have benefited by the new innovation, instead of the latter three doing so at the expense of the former, as at present.

Mr. Snell.

Mr. J. F. C. SNELL: I take a more optimistic view of the advent of the metallic filament lamp than the authors appear to do. I think it will be found to be to the electrical industry what the incandescent mantle has proved to be to the gas industry. Some time ago I took some photometric tests of incandescent gas burners, and I found that 11 c.p.-hours per cubic foot were obtained. With gas at 2s. 6d. per 1,000 ft. that really means that the cost was 0·003d. per c.p.-hour. With a 1 watt per candle-power metallic filament lamp, that means that it is equivalent to electricity at 3½d. per unit, a figure at which a great many stations are now supplying current for lighting, and a figure which I think most of them will reach. I cannot help feeling that auto-transformers and the fixing of lamps in series are temporary expedients, and I am quite sure that the inventive genius of the lamp manufacturers will produce—in fact has already produced—a lamp which will work singly on a 200- to 240-volt circuit. The authors refer to the capital invested in gas undertakings and electricity undertakings. Reading those figures one would take a very pessimistic view of the electrical industry. For instance, the capital outlay on gas undertakings is £4 10s., and on electrical undertakings £7 10s. per £1 of gross revenue per annum; but, fortunately, as the authors also point out, the ratio of working expenses to receipts is 75 per cent. in the case of gas, and only 46·3 per cent. in the case of electricity. They do not point out that the net profit from the gas undertakings only averages 5·44 per cent., whereas in the case of electricity undertakings the average is 6·89 per cent. One might argue that is due to the cost of electricity or the charges for electricity being too high, but I do not think that is really the case. If gas undertakings were in the position of the majority of our electrical undertakings, and had to pay, in addition to interest on capital, a sinking fund which, together with the interest, amounts practically to 6¼ or 6½ per cent.,

one finds that they could not do it because they would require a net profit of eight million odd pounds in order to pay 6½ per cent., and the actual sum which they have available is only £6,800,000; whereas electricity undertakings would require 3¼ millions practically, and it will be found that they have 3½ millions with which to do it. So that the electrical undertakings appear to be in a very much better position in that respect than the gas undertakings. I am one of the heretics who differ from Mr. Andrews, and also from the authors, in believing that a flat rate after all, although it is not scientifically the correct way, is *commercially* the best way of charging lighting consumers. I have had some years' experience in the provinces in a town where gas was extremely cheap, and I know the very great difficulty I had from consumers with the maximum demand indicator. Like many other station engineers, I followed that fashion, then I adopted other methods, but finally I was driven to adopt the flat rate method. I cannot help feeling that, as the supply of electricity becomes more general, and is applied to lighting, heating, and power purposes, we shall be in a better position to charge a uniform flat rate, with varying degrees of discount according to the user of the electricity. Mr. Snell.

Mr. R. HAMMOND: In regard to the metallic filament lamp, I am thoroughly with those who believe that it is a magnificent thing for the industry. We have been saying for the past twenty or twenty-five years that we should entirely abolish gas if, by various methods of economy, we could produce electricity cheap enough. We have made a fight against gas through all these years, and at last we find ourselves in a position, with the metallic filament lamp, of being able to supply electricity in England at practically a cheaper price than that at which gas is supplied. We have talked about shutting up the gas works in England for a great many years, and I would like to say to the gas managers that the invention of the metallic filament lamp makes their tenure a very short one. As long as the Gas Light and Coke Company is paying its big dividends I am very happy, because I realise thereby what an enormous field there still is for electricity. When Mr. Cripps said last year before a Parliamentary Committee that his clients, the Gas Light and Coke Company, were actually drawing £1,000,000 from their penny-in-the-slot machines, I at once said what a striking proof it was of the immense advantages which were coming to the electric lighting companies when they were able to take over the smaller consumers. With regard to the falling off in the supply of current, of course we are going as a first result to get smaller outputs in many places by the introduction of the metallic filament light. Temporarily it is a very hard thing for the industry. I provided a 1,500-k.w. set at Hackney about fifteen months ago. The plans were laid down in order that it might be working on the 1st of December to cope with the immensely increased load. Well, the load did not come; we are only doing about 100 k.w. instead of 600 or 700 k.w. more than we were a year ago. Of course we shall get over that stage, but we must not be surprised that the immediate effect will Mr. Hammond

Mr. Hammond.

be a dull one for the industry. London has not suffered very much so far, which I can prove from a few figures I have taken out. In 1901 the number of units turned out in London was 69 millions, an increase of 34 per cent. on the units of the previous year; in 1902 it was 86 millions, an increase of 23 per cent. beyond that of the former year; in 1903 it was 110 millions, an increase of 27 per cent.; in 1904 129 millions, an increase of 17 per cent.; in 1905 154 millions, an increase of 19 per cent.; 1906 shows an increase of 13 per cent.—not a falling off; and the next year, the last year for which I have the returns up to March 31, 1907, shows an increase of 12 per cent. So that we are not going back, and I feel quite confident that, by the time we have really got the metallic filament lamps well at work, immense good will come from them. The only other point I want to make is this: I am entirely with the authors of the paper in ridiculing the idea of charging for the supply of domestic power, the running of fans, heating, and the boiling of kettles—which is, I suppose, a form of heating—at a different rate from that of lighting. I can understand factories having their power at a different rate in consequence of the more favourable load factor and the diversity factor, but I cannot understand the double-meter system in private houses. I think that good will come to the industry by putting the whole of the domestic demand upon one footing.

Communicated: The point we have to arrive at is what is the form of charge which will secure to the electricity undertaking the most profitable class of consumer. We are all agreed that that class is the one that uses the light the longest number of hours. Some seem to be under the impression that this consumer can be best obtained by a flat rate. I entirely dissent from those who hold this opinion. The flat rate is the form of charge which tends to encourage the short-hour consumer, since by it he obtains his electricity at lower than cost, the loss upon his consumption being put upon the long-hour consumer.

My strong opinion is that the authors are working on the right lines, and that their proposed contract demand system is one which would abolish many of the unpleasantnesses connected with the Wright maximum demand system. I see, however, some objection to a system which might entail a constant source of anxiety upon the consumer, and I welcome Mr. Long's bright idea that each consumer should be charged a rental based upon the assessment value of his house and in addition a small running charge. The desire of the consumer to know exactly what his electricity is going to cost would almost be entirely satisfied by the general application of this system, as he could very easily be made to understand what would be the probable addition in respect of running charges for the amount of electricity consumed.

I trust that the outcome of this debate will be a determined attempt on the part of the leaders of the industry to get the Board of Trade to insert into their next Electricity Bill a provision enabling the electricity supply undertakings throughout the kingdom to make a fixed charge, whether by means of a "rate per kilowatt of maximum demand" or by a proportion of the assessment of the premises.

With regard to the "fixed rate per kilowatt of maximum demand" this has figured in all the recent power Acts and Bills, and is included in the three Bills of this Session. Mr. Hammond.

Mr. L. GASTER: At the present time two distinct views seem to be taken of the probable influence of the metallic lamps. On the one hand, it is urged that consumers will be able to obtain the same amount of light for a smaller energy consumption, and will therefore decrease the revenue of the supply company. On the other hand, it is urged that consumers will be educated to use more light than previously, and thereby extend the use of electricity. Mr. Gaster.

My own view is that for the present some compromise between these effects will take place, and the gradual development of glow lamps from high candle-power and low voltage, through various gradations, to low candle-power and high voltage, will smooth the path of supply companies.

As the authors truly state, the maximum demand system has been a frequent source of trouble to the consumer, and I would point out one respect in which I think his confidence might be nurtured. When the maximum demand system and the alternative flat rate are submitted to the consumer, as it is done in many places, he should be informed that his bill, by adopting the maximum demand, system will never exceed what it would have been if he had chosen the flat rate. By this means he is encouraged to adopt the more scientific system which the company prefers, and is rightly guaranteed to benefit by being a long-hour consumer; under no consideration will he have to pay more than his neighbour, who chooses the simpler flat rate system, except in the form of rental for the additional instruments.

I should like to comment upon the suggestions made by many that "electricity should be pushed still more for heating and cooking purposes," and to suggest that this field might be left to gas companies, as it must be remembered that an industry in which as much as 120 million pounds is invested is not likely to allow electricity to take its place for lighting purposes unless it can see a fair prospect of remunerative extension in other directions. In reality, I think it ought to be recognised that certain spheres of action are specially favourable both to gas and electricity, and some system of mutual co-operation and assistance is greatly preferable to unreasonable and unwarranted interference in legitimate fields of enterprise.

I also disapprove of the indiscriminate pushing of electricity and the new metallic lamps in all directions, whether the best thing to be employed in the circumstances or not, and wish to advocate the education of canvassers in matters of illumination. They should be able actually to assist the consumer, and also to understand the merits of other systems of illumination besides that in which they are specially interested. In reality, it ought now to be recognised that it is usually too much to expect the central station engineer, who has enough to do at the station, to be also the business manager and to attend to the requirements at the consumers' end.

Mr. Moncrieff.

Mr. K. A. Scott Moncrieff: There is one point in the paper on which I desire to make a remark, namely, the fear the authors express that the cost of the service to small consumers will have a deterrent effect upon the industry. I think one may safely say that though the cost of the service has been much reduced of late there is still great scope for reduction. Another point with regard to the small consumers is that hitherto I think when we have tried to get small consumers we have obtained the very small ones—such as municipal dwellings where the landlord puts in the light whether the tenant wants it or not. But there is a large number of houses of a bigger description, say the £35 a year house, where we have great scope for business of a paying nature. It is a matter of regret to me that the authors have not given some description of the apparatus they propose for dealing with contract demand. It seems to me that this proposal resolves itself into practically a heavy meter rental and a low charge for electricity. Possibly one could devise a meter which, when it reached its maximum rated output, would either go at double speed or switch on to another train of wheels to be charged at 8d. a unit. When reading the paper I happened to have on my table an ordinary load curve, and it occurred to me to apply the reduction to that load curve. The result was that I cut off the peak; I got the best curve I had ever seen from the generating point of view, but I also cut off all the profit. The day load on that curve was motors. I think perhaps we do not realise that vast progress has been made in the motor load, particularly in the north country. I was looking through some statistics to-day to follow this up, and I hit upon Darlington. In Darlington 38 per cent. of the output went to tramways, 38 per cent. to lighting, and 24 per cent. to the motor load. In the five years in which it will take this metallic filament lamp to establish itself that motor load is not going to stand still. Another point is that lighting by metallic filaments will reach further and will obtain a much better diversity than our present lighting provides. There is a great field in that way for extending the use of electric light, also by making it so cheap that people will waste it; this will bring down the obnoxious peak in the load. When that time comes we may hope, particularly in the North and in commercial towns, to get a very much better load factor. The lighting would then be an incident in the diversity of the load, not the predominant part of it.

Mr. Ruthven-Murray

Mr. E. T. Ruthven-Murray: I should like to have heard from the authors some particulars of their tests on auto-transformers, the use of which I also regard entirely as a temporary expedient. I have heard it stated that their power factor is very low, not more than 50 per cent. in most cases. If that were so it would be serious from the point of view of the alternating-current station; but from tests I have made, while it appears the power factor may be as low as 0·7 at low loads, it rises to nearly unity at full load. The authors say they have come to the conclusion that small consumers do not furnish a satisfactory load and cannot be profitably supplied. Among the various small supply undertakings

belonging to my Distribution Company there is one little town, which I believe has more lamps connected per inhabitant than any other in the country, in which no less than 23 per cent. of the consumers are free wired or rent their wiring. Five years ago the return on the capital outlay was 16 per cent., but it has dropped slowly until during the past year it was about 12½ per cent. While 12½ per cent. can be earned upon the capital expended on free and rental wired consumers, I think the business worth taking up, especially in districts in which otherwise progress would be very slow. Absolutely free-wired installations consisting of about six lights are a paying investment to the supply station because of the very large consumption per 8-c.p. lamp wired In such installations lamps are only put where they will be used for long hours, and from our returns I find that something like 22 units per 8 c.p. connected are consumed in these free-wired installations. I regret that the cost of the new lamp makes it impossible to retain a "free-lamp" scheme, in which lamps are supplied in lieu of discount for prompt payment of account. Such a scheme assists the supply station very materially, because the consumers never omit to replace burnt-out lamps or those giving poor light. Various systems of charging are referred to in the paper. In my opinion the real reason the maximum demand system has given so much trouble is because wiring contractors cannot or will not understand it. I know districts in which the consumer has the option of paying either a flat rate or on the maximum demand system, and it is only necessary to know the contractor's name to tell which rate will be filled in on the application form. The authors refer to Section 19 of the Electric Lighting Act of 1882, and say, in view of its provisions, they do not understand why a consumer should pay one price for lighting and another price for power. Are they aware that in many recent Orders the 4th Schedule prescribes both a flat rate of, say, 7d., and 7d.—2d. on the maximum demand system for lighting, and for power and all other purposes another rate of probably 2½d. per unit? With regard to the very simple fixed rental system of charging, Mr. Andrews' Hastings scale was equivalent to £15 per kilowatt, and 1½d. per 8-c.p. lamp. If the demand indicators are calibrated in thirtieths of a kilowatt at the declared pressure, each division will represent an 8-c.p. lamp taking 33·3 watts, and this is a convenient method of calibrating the indicators. On this system the fixed charge should be kept high and the energy charge low, because the advertising value of keeping the charge for the metered units low is enormous. With regard to the author's "contract demand," I should be sorry to have the responsibility of fixing this for any consumer! As an alternative I would suggest letting the consumer fix his own demand. This could easily be done by providing an attachment to the maximum demand indicator to enable the consumer himself to fix his demand limit, and to increase but not to decrease his demand. If his demand at any time exceeded the limits he fixed, warning would be given by the ringing of a bell or by bringing into action a flickering device or resistance such as the

Mr. Ruthven-Murray.

Mr. Ruthven-Murray.

authors have shown. Thereon the consumer could either switch off some lights or other apparatus or increase his contract demand, but in any case he will know his normal demand is being exceeded.

Mr. Gill.

Mr. F. GILL: I propose to confine my remarks entirely to the question of rating, and to assume for the moment with the authors that it is desirable to consider the question of rating and to take some steps to adjust electricity tariffs. I have not studied electric light rating, but I have during the last few years had to make a special study of rating as regards telephone work, and I think some of the lessons

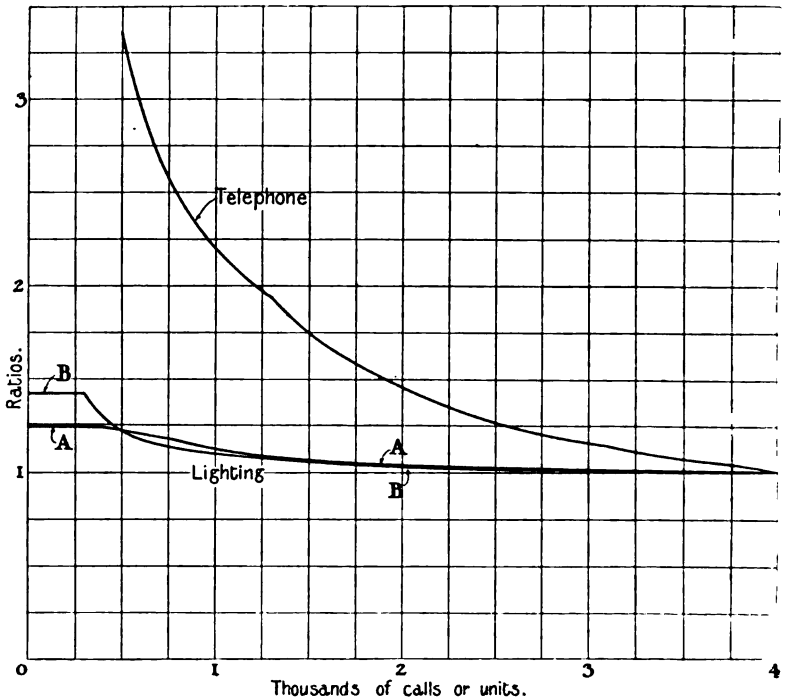


FIG. N.

learned in that connection apply with equal force to a consideration of rating for lighting systems. It seems to me that a maximum demand system of any kind acts as a discouragement to the consumer to put in lamps or other devices which he may not use for long-hour purposes.

Many persons with experience of the maximum demand system have given it up and have adopted either a flat rate or else a sliding scale. It is clear from first principles that if the flat rate be adopted, some consumers obtain their supply at less than actual cost, while others are charged too heavily; the sliding scales in force do not seem really to meet the case if the object of their authors is to approximate

somewhat nearly to a correct incidence of charge because, so far as I am able to judge, the range over which the scales slide is insignificant. Mr. Gill.

The diagram (Fig. N) illustrates the very important difference in this respect between telephone and lighting practice. A and B represent two published lighting scales, and the third curve is a scale for telephone service. The curves are carried out to 4,000 units per quarter for lighting, and 4,000 calls per annum for the telephone; the average price at 4,000 is called unity, and the curves show the relative cost at which the average unit or call is sold, according to the quantity taken.

In case A the price commences at 4½d. per unit and falls by successive instalments, being purchased at 4d. after 400 units, and 3½d. after 800 units, until at 4,000 units the average price is 3.65d. per unit. In case B the price commences at 5d., after 300 units the balance is purchased at 3½d., and at 4,000 the average price is 3·61d. per unit. In the telephone case the minimum number of calls is 500 at 2·88d. per call, and the price for further calls successively falls, so that at 4,000 the average price is 0·86d. per call. The three are sliding scales, but it is clear that the telephone "slides" much more than do the other two. If a consumer reduces his consumption, say, by 25 per cent., from 4,000 to 3,000, the increase in the average price per unit is in case A 1¼ per cent., and B 1 per cent., an increase which is useless, while in the telephone case the increase is 15 per cent.; in the same way, if the consumption falls by 50 per cent. from 4,000 to 2,000, the increase in the average price is for A 4 per cent., B 3 per cent., and in the telephone case 46 per cent.

Of course the telephone scale only does to some extent what the maximum demand and contract demand systems do, but I think it does it in a simpler way; it takes into consideration the standing charges, the cost of getting ready to serve, and then the lower subsequent cost of giving the service after it has been established; the same scale is appropriate to the large as well as to the small consumer—the larger the use the lower is the average price per call.

Mr. R. BORLASE MATTHEWS: In the course of their paper the authors say that "it is very doubtful if there are many districts where the number of consumers could be *quickly doubled*, whatever may be the result in the long run." A statement to which exception may be taken, since there are very few places in this country where the revenue could not be very largely increased, say in two years, if a properly organised Publicity Department adapted to local requirements were inaugurated. The period of two years is mentioned because it takes pretty well one year to get such a department into proper working order, and to educate the inhabitants of the district to the required point. Mr. Matthews.

The authors refer to the cost of an electric service being £5 to £6. This is a figure that will have to be reduced. One company in the neighbourhood of London has already brought its average service connection cost down to £4. Reliable meters for house service can now be obtained for £2 or less each, and prepayment meters at £1 10s.

Mr. Matthews.

each, so that there are good prospects of reducing this serious item to some extent.

Tariffs will have to be stated, if they are to be best appreciated by consumers, in three different ways, to suit (1) householders, (2) shopkeepers, (3) power users.

That for the householders must meet with the conditions that—

(*a*) It is immaterial how many lamps are connected, and should encourage the use of electricity all over the house.

(*b*) There must be no restriction as to use that checks waste on the part of the consumer.

(*c*) It must be simple, easily understood, and be such that the cost of current may be readily estimated in advance.

(*d*) One circuit only will be needed for lighting, heating, cooking, and power.

(*e*) One meter only is required for all household purposes.

These are not easy conditions to comply with, and do not at first sight appear to fall in with the ideal requirements of supply from the central station standpoint. It is much easier to lay down the requirements from the consumers' point of view, than to suggest a tariff that will comply with them.

The tariff for the shopkeepers can best be based upon the use of an hour meter for the window and outside lighting, with discounts for excess use of over a certain number of hours; and also either an hour meter, or a basis similar to that suggested for charging house consumers, for the interior lighting, heating, etc., such a system being readily understood, easily calculated in advance, and encouraging after-business hour lighting for advertising purposes. The rate on the hour-meter system would, of course, be determined by the capacity of the apparatus connected on a "readiness to serve" and "cost of generation" basis. If the hour-meter rate can also be made to include the cost of trimming of arc lamps, it will lead to an increased use of the lamps.

The method in which the tariff for the power users is expressed, need not be simplified to the extent that is necessary for householders and shopkeepers, as power users are more accustomed to scales of charges that deal with discounts for increased use and steady average demand.

In reference to the various systems of charging at present in vogue, the authors say that many engineers often overlook the fact that it may be more profitable at times to let a very short-hour unremunerative consumer go. This may be so, but the fact must not be forgotten that the loss of a consumer is a very bad advertisement for the undertaking, and often prevents other consumers from coming on.

Mr. Mordey

Mr. W. M. MORDEY: I would like to make one very small suggestion in the direction of simplicity of words, and it is that we should call these metallic filament lamps "wire lamps." I think it would be better, now that we have got this new lamp, to simplify its name, and call it what it is, a wire lamp, using a simple one-syllable

Anglo-Saxon word. I agree with those who think the wire lamp is going to do a very great deal for electrical engineering. I cannot believe that the increase, by two or three times, of the light for a given current, can be anything but a good thing for the industry. There may be a little dip in the curve, but the curve must go on rising, and rising very much more rapidly when people realise what they have really got. It must make the comparison with gas so much more favourable to electricity. On the question of charging I would like to support what Mr. Arthur Wright advised at the last meeting; he advocated imitating the broad lines of the Gas Companies, and doing away with self-imposed restrictions. Coming from Mr. Wright one naturally attaches very great weight to this advice. It may be that he has seen what the authors call "the theoretically more perfect system" of maximum demand is not theoretically perfect after all. It is significant that people do not apply it to power, and even as regards lighting they offer to short circuit the demand indicator at times of maximum demand. Mr. Wright read an interesting paper in 1901, on which I spoke. I have been looking up my remarks, and I find that at that time there were three demand stations to one flat-rate station. Looking at the tables in "Lightning," I find now that we have one demand station to three flat-rate stations. A new or optional class has now come in, so that there are now three classes; and the proportions are three optional, three flat, and one demand, so there has been a gradual change of opinion on that subject. The average prices obtained in these three classes are flat-rate, 3.57d., maximum demand, 3.33d.; optional, 3.33d. In the discussion on Mr. Wright's paper I made a comparison, and I have made a similar comparison now, which shows that, taking the average of the stations, the demand system does not give what it is supposed to do. For example, it does not improve the load-factor. The load-factor now comes out 15·05 for flat-rate, 14·82 for maximum demand, and 15·75 for optional stations. I find that since 1901 the output has gone up four-fold—to 674,000,000 units; the average works cost per unit has gone down to 0·802d., a third of what it was then. I think that is a very satisfactory result of six years of work of the electric-light stations in this country. The output just given does not include the big Newcastle station, nor any railway or tramway or power stations. I would like to say that without criticising the authors' suggestions, I believe it better to simplify as far as possible all installation work, to reduce the cost of getting into the houses, to avoid all auxiliary or non-productive accessories, and to simplify the methods of charging as much as possible. Mr. Long's contribution to the discussion seems to me to be a very valuable one.

Mr. Mordey.

Professor DAVID ROBERTSON (*communicated*): The following is put forward as an equitable way of charging for electricity supply which is free from the defects of the Wright maximum demand system, and obviates the use of demand or limit indicators, or of special meters for different uses. A nominal load would be fixed by the consumer, as a

Professor Robertson.

Professor Robertson.

rule with the assistance of the officials of the supply authority, and he would contract to pay a minimum sum proportional to this load each quarter or each year. The meter would be adjusted so that it registers at the nominal rate when the consumer is taking his nominal load, but at a higher rate with a larger load, and a lower rate at lighter loads. The standing charges may be taken as proportional to the demand. The revolutions per unit should therefore follow a linear law with the load instead of being constant, the constant part would represent the running charges, and the remainder the standing charges, profit being included in one or both. With many types of meter there would be no difficulty in making an adjustment of this sort. In fact, they have naturally a law something like it, and have to be compensated for ordinary use.

The guaranteed sum, which should include meter charges, as should also the charge made for energy, would be that which would be brought in by the nominal load used for the number of hours per year, or per quarter, assumed when fixing the nominal rate of charging. This method would take some cognisance of diversity factor, for no account would be taken of occasional heavy loads, whose diversity factor would probably be high, when determining the nominal load proper to any particular case. The correct nominal load would make the consumer's bill a minimum; the guaranteed sum prevents his getting his energy too cheaply if his load factor is less than he expects, while his energy will have to be paid for at a higher rate than necessary if he keeps the guarantee too low.

On the other hand, he is not deterred by increased annual charges from installing lamps in places where they will be little used and whose diversity factor is generally very high; he does not have to instal an illogical and expensive double system of wiring if he wishes power as well as light, and he is, therefore, much more likely to use heating apparatus, cookers, etc.; and he is not penalised for occasionally having all his lights on, beyond paying at a higher rate for the energy then actually used. From the supply authority's point of view, these advantages are of use in inducing new consumers to come on the mains, or old consumers to instal further apparatus; the expense of demand indicators and separate meters for power is avoided; and the load curve will probably be improved, for when the consumer understands that the more lamps he has on at a time, the more he has to pay for each, and *vice versâ*, the more likely is he to keep his peak down and the less likely to economise when his load is light.

Mr. Bowden.

Mr. J. H. BOWDEN (*communicated*): The subject of this paper is one to which I have given considerable attention during the past few years, and in 1906 I published jointly with another an article dealing with a system of "Equitable Charging by Municipal Undertakings,"* in which there are phases of the subject which the authors have probably not considered. Possibly I am placed in a unique position, having control of an undertaking possessing a power load which preponderates

* *Electrical Review*, Vol. 59, pp 323–4, 1906.

over the lighting load, and must, in consequence, view the question from a standpoint totally different from that of the authors. Mr. Bowden.

During the current year I estimate that the maximum demand for power on the popular undertaking will be 1,700 k.w., and the output 4¼ million units, equal to a load factor of 28·54 per cent.; private lighting 1,000 k.w., and the output 1 million units, equal to a load factor of 11·41 per cent.; and public lighting 200 k.w., with an output of ¾ million units, equal to a load factor of 42·81 per cent., making a total maximum demand of 2,900 k.w., with an output of 6 million units, equal to a net load factor of 23·62 per cent. I anticipate that the average price received will be, approximately: Power, 1·05d.; private lighting, 3·43d.; and public lighting, 1·5d.; or a net price of 1·52d. The diversity factor for power upon this estimate is 3·75, private lighting 2·5, and public lighting *nil*, or a net diversity factor of 3·06, with a total of 9,075 k.w. connected.

The standing charge will be, approximately—

Interest and repayments	£15,000
Other charges	7,000
	£22,000

and I wish to show a net profit of something in the nature of £4,000, making a total standing charge upon the consumers of, say, £26,000, whilst the running charge will probably be about 0·45d. per unit. According to the principle laid down by the authors, each consumer should be charged a proportion of the standing charge equal to the extent of the maximum demand he may possibly make upon the station, that is, the capacity of his total connections, although in their examples they do not adhere to that principle. By this system the charge at Poplar should be £2 18s. 6d. per kilowatt connected and 0·45d. per unit, which is equivalent to the income receivable from the average prices enumerated for power, private and public lighting, but which would alter those prices as follows:—

		£
Power connections	1,700 × 3·75 = 6,375 k.w. at £2 18s. 6d. =	18,647
	4¼ million units ... at 0·45d. ... =	7,990
	Total	£26,637
	Average price per unit 1·5d.	
Private lighting ...	1,000 × 2·5 = 2,500 k.w. at £2 18s. 6d. =	7,312
	1 million units at 0·45d. =	1,880
	Total	£9,192
	Average price per unit 2·21d.	
Public lighting ...	200 k.w. at £2 18s. 6d =	585
	¾ million units at 0·45d. ... =	1,410
	Total	£1,995
	Average price per unit 0·64d.	
Net income...		£37,824
	Net average price 1·52d.	

Mr. Bowden.

It will be observed that the authors' system would reduce private lighting by 1·22d. per unit and public lighting by 0·86d., but the price to power consumers would be raised on the average by 0·45d. to produce a similar net profit in each instance. In this statement 71 per cent. of the business is for power purposes upon which the metallic filament lamp has no effect, and yet it is proposed to impose a tax upon that class of business to the extent of 43 per cent., which is, to say the least of it, impracticable.

The whole paper, in my opinion, is based upon a misconception of the fundamental principle of equitable charging. It is the correct axiom that each consumer should pay a fair proportion of that cost which is specially created for the purpose of meeting his demands irrespective of the purpose for which he requires the current. The authors very clearly show the absurdity of differentiating between heating and lighting on private premises. Perhaps the greatest hindrance to the development of electricity is this class distinction between light, heat, and power, as it is matterless to the undertaking for which purpose energy may be required. But it is impossible to compute the actual value of each individual connection to a system unless the demand is constant throughout the year, and it is, therefore, necessary to resort to classification and allocate to each class its full share of the standing charges as ascertained by the maximum demand upon the station. Public lighting and 100 per cent. load factor power consumers have no diversity factor, and therefore the standing charge applicable to this class of supply is easily ascertained, a cheap supply being obtained by virtue of the load factor only. Lighting for offices, shops, and other business premises of that class should also be governed by load factor and prices fixed according to business hours. The charge to power users giving an intermittent load must be governed by diversity as well as load factor; the efficacy of this is exemplified in the records of the Poplar undertaking, which has the greatest demand of this class in the metropolitan area.

But it is the method of charging for domestic purposes to which the most serious consideration must be given. Here is a field capable of enormous development in which cultivation has barely begun.

Metallic filament lamps will do much, but cheaper and more perfect cooking and heating appliances will do more in this development, and before we can hope to have the latter, central-station engineers must make up their minds entirely to separate this class of supply from all others and charge upon its merits. Personally I am of the opinion that the authors propound the rudiments of the correct system, and that the time is not far distant when it will be feasible to separate the standing charges in such a manner as to allocate the cost of each individual service and fix an annual service charge to each consumer.

The authors are to be congratulated upon introducing a subject of more than everyday importance, and I hope in their reply that they will view the matter in a more cosmopolitan manner than they have

done in the paper; they have looked only from the West End, but others are compelled to look at it from the East End point of view. Mr. Bowden.

Mr. C. E. SKELTON (*communicated*): The paper seems largely to resolve into a plea for higher prices for current sold. Mr. Skelton.

As respects this plea in particular for the time of peak of load, I do not envy the task of him who seeks to convince the British public that one unit of current is worth more, say, between 5 p.m. and 7 p.m. than at any other hour of the day; it would be nearly as wise for a restaurant proprietor to ask for increased prices at the time of his peak of load.

Much has been done in connection with the costs of production, but cannot even more be done? If uniformity of pressures of supply could be achieved, would it not tend greatly to reduce the costs of manufacture of dynamos and so lessen somewhat station capital outlay? Further, would it not greatly reduce the costs of motors, heating and cooking apparatus, and even of lamps, and so result in much larger installation of such? What can be more foolish than the following condition of things in a street not a quarter of a mile long? One side has 200 volts and 100 volts, the other side has 104 volts and 150 volts, this latter being changed to a supply at 240 I believe.

To abolish the need for dual installations for light and power, together with reduction of costs of apparatus, which would result from a uniform pressure of supply, and uniform installation requirements by station engineers, and fire offices, would bring about a large increase in demand and use; an increase not by any means confined to the time of peak of load; an increase which I venture to think would astonish supply engineers.

Mr. J. E. TAPPER (*communicated*): It is remarkable that on the question of metallic filament lamps the majority of engineers show a wonderful optimism, and appear to believe that the introduction of these lamps is going to be the saving of the industry. In districts where gas is greatly predominant, and where new buildings are springing up, it may be so in course of time, though even to these the temporary set back is likely to be serious, but to the alternating-current undertaking supplying a purely residential district such as the one of which I have an intimate knowledge, the outlook is, to say the least of it, alarming. Mr. Tapper.

In the district supplied by the station referred to one house in six is already supplied, against an average all over the country of only one in ten, and the prospect of picking up a sufficient number of new consumers to cover the immediate loss is very remote. Under-estimating the position if anything, it is quite possible for the 1,200 consumers at the station referred to, to effect a reduction in their total consumption of 25 per cent. To give the same revenue, therefore, as at present, 33⅓ per cent. in consumers must be added to the mains at a capital cost of £3,500 for services only, or an additional annual charge of £200, plus extra cost of maintenance of services and collection. During the years occupied in securing the additional consumers it is possible that the undertaking may have to run at a loss unless either meter rents or the prices charged per unit are raised.

Mr. Tapper

The whole thing boils down to this: if the finances of the station will not allow of a reduction in the charge for current supplying ordinary carbon lamps, then they cannot stand the reduction in consumption due to the metallic lamps, and either meter rents or current charges *must inevitably be raised.*

A serious feature, but one which may prove only temporary to alternating-current stations, and which has been dealt with but lightly, is the introduction of small transformers. These, being cheaply designed on the economy coil principle, give a very low power factor unless worked at full load.

Mr. Shaw.

Mr. A. H. SHAW (*communicated*): With regard to supplying small consumers which the authors refer to, I have had some experience of this at Ilford.

About six years since, when we had some money available for wiring purposes, we adopted a scheme of free wiring for small houses, fitting six lights in the principal rooms and supplying them through slot meters set at 1d. per unit above the usual rate for current to cover the rental of installation, meter, and supply of lamps, etc. We fitted up about one hundred houses on this system before our money was expended. As a result we were able to get builders of similar property to wire their new houses during erection. On one estate all the houses, letting at from 7s. 6d. to 9s. per week, were fitted with four lamps each, which we supplied through separate slot meters, running one service into each block to supply from ten to twelve houses. For some years the results obtained were fairly satisfactory, although but little profit was made, as the cost of collection and looking after the meters was very heavy, and in several cases when the meters stopped running, but did not switch off, the consumer obtained current for a month or two free of charge, and we found it impossible to make him pay up later. Recently, however, the local gas company have introduced a system whereby they supply a gas cooker and four burners free of charge to such houses through a slot meter at an increased rate, but they refuse to supply on this system to any one who is using electric light, and as a result we have during the last eighteen months lost a large number of these consumers. My experience in this direction has compelled me reluctantly to come to the conclusion that the supply to this class of property is not worth while under present conditions when everything is taken into account.

With regard to the system of charging proposed by the authors, a preferable method, in my opinion, would be to base the demand charge on the readings of a demand indicator, fixing a minimum at, say, 0·5 k.w. at a fairly high rate, and adopting a sliding scale for higher demands, the extra charge for, say, each ½ k.w. decreasing as the demand increases, the unit charge being fixed at, say, 1d. per unit for all current consumed. With regard to the supply for power purposes and tramways I consider a separate rate would still be found preferable for these purposes, and is justifiable taking into account the diversity and load factors.

Regarding heating and cooking appliances, I have found that in medium size houses the tendency is to use these more during the summer, when we can best afford to supply them at a low rate, than during the winter when fires are used for all purposes, including kettles, flat-irons, and the like; but in the summer it is not desired to light a fire merely to boil a kettle or heat an iron. I therefore consider it quite justifiable to supply current for these purposes at a lower rate than for lighting. Mr Shaw.

Regarding the small house transformers referred to, I should be glad to know if the authors have made any tests of the load factors of these. I have been informed that the load factor of such transformers is very low, in some cases no more than 0·3, and if this is so and they are adopted to any extent, it will have a very serious effect upon alternating-current supply stations. In such cases I think it would be permissible to make a special increased rate for supply to such transformers.

Mr. W. R. COOPER *communicated*): No doubt engineers will differ very considerably in their views as to what the effect of the metallic filament lamp will be on the electrical industry, but, whatever our individual opinions may be, I think that engineers should be grateful to the authors for bringing this subject forward so that it may be fully discussed. It is a curious fact that we have all been most anxious to see the advent of a high-efficiency lamp, but now it has come it is not universally welcomed, except by the consumer. In fact, the station engineer is apt to regard it as an evil. In this connection it is worth while to remember that the consumer has suffered somewhat patiently for a good many years; therefore it is only right that he should begin to benefit. Some years ago the station engineer introduced high pressures, much to his advantage; but the consumer, on the other hand, was compelled to use comparatively inefficient lamps in consequence. In the long run, no doubt, the consumer benefited to some extent. He may now get his energy at 4d. per unit instead of 6d., but, on the other hand, he has been compelled to use 6 units where 4 units ought to have been sufficient. Mr. Cooper.

Nevertheless, we do not wish to see the station engineer in any way hampered. Personally I am inclined to think that the drop in revenue due to the metallic filament lamp will not, as a rule, be serious. For example, on continuous-current systems the units of light available will be too large to allow any great diminution in the amount of current used, except in special cases; and, although metallic filament lamps are certain to improve and smaller units will no doubt be introduced, the change will be gradual. On certain alternating-current systems, on the other hand, where the load is chiefly due to light, there may be a serious falling off in revenue. No doubt, in time this will be compensated by the very large additional field rendered possible in street lighting and small shops; but, meanwhile, the position in some cases may become serious. Nevertheless, I think that it would be a very great mistake to restrict the consumer in any way by binding him to have more light for the same current, and I think that

Mr. Cooper. the raising of prices should be adopted only as a last resource, owing to the bad effect that it might produce in other directions.

One of the most important points raised by the authors is that of the small consumer. It has always been thought that the small consumer would present a ready field as soon as a highly efficient lamp could be found; but it will be a serious matter if the cost of services to such consumers is so great as to render them unremunerative. Such consumers have been supplied quite successfully on the Continent, owing to the very cheap way in which services are there run, and, although we may not be able to adopt overhead wires in towns in this country, it appears to me that it should be possible to supply services for blocks of houses very much more cheaply than is done at present. In this country we are so accustomed to carrying out electrical work in the best possible way that we are apt to forget that such work finally may become unremunerative. Similarly, the cost of internal wiring must be reduced, and there seems to be very little reason why the Continental system of using unprotected insulated conductors should not also be imitated in many instances. This, however, will never be brought about until the station engineer gets into touch with the contractors and arranges with them what is acceptable. At present no such work can be done because it is nobody's business to do it. The station engineer looks upon such wiring as inferior and will not pass it, and, naturally enough, the contractor will not carry out such work with the risk of it not being accepted.

With regard to the important question of tariffs, much may be said in favour of the author's system. Undoubtedly the distinction between the different uses to which electrical energy may be put is often absurd, as the authors point out; but, from the point of view of household supply, I think that the greatest defect in systems at present in use is that they do not distinguish between different parts of the day. The only time when a heavy load is not desirable in a house is at the time of peak load at the station. A heavy load at any other part of the day would be welcomed by the station engineer; but any system depending upon a maximum demand prevents the ready use of electrical energy during these other times of day, and thus seriously hampers the use of electrical energy for other purposes. As the extended use of electrical energy for heating and cooking would mean a much larger consumption for a household than that required for lighting, I think that this phase of the tariff question should be given serious consideration.

The President. The PRESIDENT: This paper deals with matters that I have studied rather closely for twenty years. It is interesting to note, as might be expected, that the effect of the introduction of metallic filament lamps is viewed with favour or disfavour according to each speaker's special experience.

I am afraid that the coming of the wire lamp may cause a distinct set back to the electrical industry. We are not now in the position of ten years back. We have already made such reductions in the working expenses and cost of supply as far as they can

be effected by the engineer that there is not much margin left for further reduction. For future reductions we have to depend mainly on improved outputs due to improved load factor. The wire lamp will very probably for some years diminish the lighting demand, and will not help us with the load factor. Unfortunately I think it is not sufficiently realised by the general public, and even in this Institution, what great efforts have been made in the past to improve load factor, and I am sorry to say with disappointing results. The heating load has not helped us; the power load has only helped industrial districts. As regards the working expenses themselves, I am afraid the outlook is not good. There are those who tell us that the cost of fuel is likely to be permanently increased, and of one thing we are quite certain, that the very heavy charge we pay to the public authorities in the shape of rates, which amounts on the average to 10 per cent. of our gross earnings, is much more likely to increase than to diminish. The increases on these two items alone are likely to more than outweigh any future improvements we can introduce by improved machinery. The President.

For this reason I think the authors are right in coupling with this subject the interesting one of electrical tariff reform. At Norwich they are paying for electricity as we have always paid for our water, mainly by a rent charge and to a certain extent by metered quantity. I cannot help thinking that when our large London undertakings pass into the hands of the local authorities at the end of our concessions, that the local authorities will then follow the example of the Water Board and supply and charge for electricity on the Norwich system, or on some modification of it. If, then, this system is likely to be introduced some years hence, why should we not set about considering its introduction as soon as possible?

Discussion at Dublin, April 9, 1908.

Mr. R. N. Tweedy: So far as alternating-current circuits are concerned, the new lamps may be used to the greatest advantage by consumers who are wise enough to believe the statements of the wiring contractors. Undoubtedly a large proportion of consumers consistently shut their ears to anything they may say, but we must all realise that it is a great deal to ask a layman to believe, when we assert that he will save something between 30 and 60 per cent. of his electric lighting bill by using another kind of lamp, and we ought to be very thankful to the authors of this paper for coming forward with unbiassed testimony. When the consumer gets to know that supply companies are being forced to consider the advisability of raising prices as a set-off against the reduction in output caused by the vast number of metal filament lamps connected to their mains, he will realise that the contractors' statements are reasonable, and the sale of these lamps will improve still more. Mr. Tweedy

That there is now, and will be to a greater extent in the future, a

Mr. Tweedy.

reduction in the units sold per lamp connected on alternating-current mains is not in doubt, but the matter assumes quite a different aspect when direct current is involved, and I may be permitted to question whether, up to the present, the engineers of direct-current stations have been assailed by the same fears which seems to have attacked the authors. Assuming that the bulk of the lighting load is derived from private houses, and that supply is given at 200 volts or over, it is not probable that the carbon filament lamps will be superseded for some considerable time, for the reason that the average private consumer does not want 60 to 70 c.p. where he is now content (or as content as a private consumer ever will be) with 16 or 25 c.p. At present he must burn two of the new lamps in series. So long as the consumer has to face the disadvantages of burning either high or low candle-power lamps in series the decreasing output problem will not much touch the direct-current station.

I would like to put in a word of protest against the short-sighted policy of wiring a building in anything like a permanent manner for the use of lamps in series. I believe that has been done even in Dublin, where series burning is absolutely unnecessary. There can be no objection to the use of adaptors, or to wiring lamps in series from the permanent parallel points; but we must all look forward to the advent, sooner or later, of a high efficiency moderate candle-power lamp which will burn in parallel on 200 volts.

I observe that the authors propose to deal with the problem of reduced output per lamp, and with the very important problem of how to popularise electric heating by the invention of a new tariff. What we really want, and what we ought to have, is a tariff which shall not study the equity of each case too minutely, but shall first and foremost pay the suppliers a reasonable profit under every condition.

Mr. Cummins.

Mr. C. J. CUMMINS: Speaking as a contractor, I consider the advent of the osram lamp is the salvation of electric lighting. No doubt incandescent gas lighting has educated the public to better light, and I believe that existing customers will now extend the use of electric light on their premises. Regarding the saving effected by the use of osram lamps, I may mention the following cases, which are all quarterly accounts for December last using osram lamps, and for the previous December quarter using carbon lamps (in most cases the light was greater than formerly):—

	Carbon.	Osram.	Saving.
	£ s. d.	£ s. d.	£ s. d.
1	4 10 0	2 10 0	2 0 0
2	15 0 0	9 0 0	6 0 0
3	42 19 6	16 13 4	26 6 2

I do not believe in the use of 25-volt osram lamps in conjunction with equalising transformers, as I think that the smallest light unit used should not be less than 25 or 32 c.p. In my experience osram lamps are not so fragile as stated. I have not obtained good results with tantalum lamps on alternating circuits, but have not yet gained experience with the new ones recommended for use on alternating-current circuits, in which I notice that the filament is made in wave-form, evidently with a view to allow for the apparent shortening of the filament which is observable in the older types of tantalum lamps after burning some time. Mr. Cummins.

Mr. G. F. PILDITCH: I consider that there is really no cause for alarm on the part of station engineers. Private consumers really require more light, and far more complaints are received due to insufficient light than to the amount charged. When the public find they can obtain more light for the same money they will go in for it rather than reduce their accounts. I consider the proposed new system of charging excellent from the supply authorities' point of view, but not from the consumers'. Consumers talk together and compare their bills, and if one is charged at a higher rate than his neighbour he will soon get to know of it. In nine cases out of ten it will be quite impossible to satisfy him that he has not been overcharged by any explanation as to his "contract demand." Mr. Pilditch.

Mr. J. W. BOUCHER: I think that central station engineering, in raising the pressure of supply a few years ago, did not act fairly towards the consumer, as lamps supplied for low-voltage circuits were considerably more efficient. I entirely disagree with the previous speakers that the ordinary standard of illumination has risen from 16 c.p. to 32 c.p. I have had many inquiries from users of the 30-c.p. lamp as to how the light could be shaded down. For private house lighting a soft, restful light is required; therefore, although the 30-c.p. 100-volt metal filament lamp may be useful for lighting shops and large areas, it is unsuitable for private house lighting. Mr Boucher.

Favourably for the supply station must be taken into account the no-load losses on the transformers. Taking this at 20 watts for 8,000 hours, equal to 160 units per annum at 4d. per unit, this works out at £2 13s. 4d., which the consumer pays for the use of the transformer, and an all-day load has been created. Of course, the idea of switching out a transformer by a consumer is one that would not be carried out in practice.

I do not agree with the authors of the paper that an electrical undertaking is handicapped by the excessive cost over gas of bringing the mains into the consumers' premises. We in Dublin, and in a number of other cities, pay 10s. per annum meter rent. The cost of the meter is about £3, the cost to the electrical undertaking for installing, say, as given in the paper, £5 to £6, so that 10s. per annum from the consumer pays over 5 per cent. on the cost of the meter and the service combined.

I consider the contract demand system unworkable, and not founded on a proper commercial basis. That the consumer should be asked to

Mr. Boucher. pay for the privilege of call, and for what he might not use, whether he used it or not, is absurd.

Mr. Tatlow. Mr. W. TATLOW: I do not think that in the case of towns where there are many possible consumers not yet taking a supply the effect of the introduction of metallic filament lamps will be detrimental to the electrical supply companies, but rather the reverse. In Dublin the new lamps make electric lighting cheaper than gas for lighting points of 30 c.p. and under, and in consequence electric lighting will be adopted for lighting cellars and dark basements, and for all-night lighting where gas has hitherto been used, and this will be a very desirable class of load for the power station.

I do not consider the maximum demand system of charging satisfactory from any point of view. A 2-rate meter seems to be a much more sensible way of dealing with the matter, the units used during the peak being charged at a higher rate.

Mr. Porte. Mr. A. E. PORTE: I agree with other speakers that the public require more light, and will pay for it. What is lost in lighting would probably be made up in the more extended use of radiators, etc. I agree with Mr. Tatlow that the 2-rate meter is the best and most equitable system of charging.

Mr. Sowter. Mr. W. J. SOWTER: I know very few consumers who actually understand the maximum demand system, and those who do give the most trouble. I do not think consumers will take kindly to the "contract demand system," and if a change is necessary I think it will be better in many cases to revert to the old contract system without meters. Such a course will, in my opinion, be quite feasible in the case of small private house consumers, for it is just in these cases, as the authors have pointed out, that the difficulties occur in making a profit. The great difficulty I foresee in making up for the loss of revenue caused by the use of osram lamps is that of getting people to go to the expense of wiring their houses; some cheap system of free or deferred payment wiring is necessary, and at the same time the cost of mains and services must be reduced to as low a level as possible. It will be a great mistake to raise the price of current, as now is the time to prove the cheapness and advantages of electric light compared to gas.

DISCUSSION AT GLASGOW, MAY 12, 1908.

Mr. Lackie. Mr. W. W. LACKIE: I am pleased to note that the authors approve of the maximum demand system of charging, although I disagree as to their method of getting at the maximum demand. The title of the paper seems to me somewhat misleading, and I think the conclusions arrived at regarding the effect of high-efficiency metallic filament lamps on electricity supply stations require further consideration before being entirely accepted. The authors point out that if the consumption of energy per consumer is reduced through the use of metallic filament lamps by one-third, it will be necessary, in order to bring in the same revenue, to increase the consumers by some 50 per cent. owing to the increased capital outlay on services and

the increased expense for meter reading and general administration. But the cost of meter reading and administration at present is a small fraction of 1d. per unit, and what I feel is that if metallic filament lamps are made of such a size as to be suitable for all voltages, the increased consumption on existing branches and service lines and meters will in a very short time bring up the revenue to what it was before their introduction. The present tendency undoubtedly is to get increased lighting without increasing the electricity bill; and seeing that the minimum candle-power of metallic filament lamps is something between 40 and 50, the lamps are unsuitable for introduction into the many small areas which are perfectly well lit with much less illumination than this. What the authors state with regard to the relative capital expenditure and revenue of gas undertakings, as compared with electric undertakings, is quite true; but the argument cuts both ways, for if an electricity undertaking cuts down its capital expenditure per kilowatt, it is enabled to supply at a very low price, whereas the cutting down of the capital expenditure in a gas undertaking does not materially reduce the price of gas. I believe that reason No. 2 on page 336 is not correct, as gas undertakings in Scotland, at least, are liable to be bought up at any time, and under local authorities they have a sinking fund in the same way as an electricity undertaking. The authors go on to point out that a gas supply is given on a flat rate. That is not always the case, and it may be of interest to note that the Glasgow Corporation recently agreed to offer gas for power and heating purposes at 3d. per 1,000 cub. ft. less than for lighting purposes. The gas department is able to supply gas at a flat rate at present, because it can store gas to meet the maximum demand, and also on account of its splendid load factor on the works. I have no doubt whatever that if we could store electricity profitably we should also approach a flat rate of charge. The latter part of the paper deals with a new method of applying the maximum demand system. I think the example given to show the inherent absurdity of supplying lighting and heating at different rates is weak. One hot plate is taken as a criterion of the demand for heat or power, but, even so, is not the said hot plate likely to be used regularly throughout the whole year, while the lighting is only required for three or four months in the winter-time, if the dinner hour is at the time of peak load on the electricity works, which is not likely to be the case. The authors ask, Why should the current consumed for power at peak time be charged at a lower rate than lighting energy? My reply is that in the case of the lighting units the standing charges are only spread over a comparatively small number of hours in the winter months, while the standing charges for power and heating purposes are spread over some 2,000 hours in the year, and in the case of power the diversity factor is very much greater than in that of lighting. The authors again illustrate their point by instancing a small electric lift in a private house. We have in Glasgow something like one hundred passenger hoists, which

Mr. Lackie.

Mr. Lackie. are intermittently used from 9 a.m. to 6 p.m., or 9 hours a day. The consumption for each hoist shows that its load factor is not more than 6 per cent. yet the effect of all those hoists joined to one common source of supply makes a load factor on the station of 20 or 25 per cent. No such combination can be got with a lighting supply. All the bad load factor lighting comes on naturally and inevitably when the hours of darkness set in. If the supply authority does not want to take on the short-hour consumers, who they think would be unprofitable, they can quite easily deter them by quoting Section 21 of the Electric Lighting Order, 1890, which states that the supply authority may make the applicant enter into a contract for a period of at least two years for such an amount that the payment to be made for the same at the rate of charge for the time being charged by the undertakers shall not be less than 20 per cent. per annum on the outlay incurred by the undertakers. I take it a municipal supply, at least, is there to supply every one on reasonable terms, and that through all the consumers being joined together some little benefit will result, although they may be all short-hour consumers. With the authors' system of applying the maximum demand system I entirely disagree. They propose to make the supply engineer or station manager the instrument for fixing the maximum demand of each consumer. I consider this quite impracticable. The effect of the diversity factor on the standing charges is shown, but if applied by the method suggested it strikes me that the lighting consumers would be getting the benefit of the diversity factor of the power load, and the energy at a lower rate than if the power consumers were not there. The diversity factor in a lighting supply is very much less than in a power supply, hence the power consumers should get the benefit of the circumstances they create. I am quite sure that the method of applying the maximum demand system suggested in the paper would lead to very much more confusion and discontent than is the case with Mr. Arthur Wright's method. The result of charging up the fixed charges in one sum, say, once a quarter, would mean that the winter and summer bills for current would be very much alike. It would mean that many lighting consumers would get in a bill for electricity, say, at the end of the summer months, when, as a matter of fact, they would be conscious of having consumed no electricity whatever since paying their former bill. Mr. Wright's system spread the standing charges over four hundred to five hundred equal payments, and on the whole this does not lead to any great trouble. I am sorry the authors have raised the bogey about the consumer unconsciously raising his maximum demand through inadvertently turning on a few extra lights. We have hundreds of consumers in Glasgow whose maximum demand has remained the same for years, although a fresh record is taken once a year, and the maximum demand is not equal to the number of lamps installed.

Mr. Robertson. Mr. J. A. ROBERTSON: At Greenock we are in the happy position of having a large power load so that we are not affected to the same

extent as those who have to rely on their lighting business. In many cases, however, we have found during the last quarter that our large customers are reducing their bills appreciably by the use of metallic filament lamps, and if we were relying solely on our lighting business I would have no hesitation in recommending my Council to increase the price per unit. On the other hand, there is no doubt at all that the introduction of these lamps is going to be of tremendous benefit. We have only touched the fringe of the lighting business as yet, and, provided that we can find cheaper methods of laying our services and obtain a less costly meter than is available at present, we have only to wait for a year or two to find that we are beating incandescent gas out of the field. This will certainly be the case at least for shop-lighting and in all but the very smallest class of dwelling houses. As an instance of what metallic filament lamps can do, I may state that in the latter part of last year we connected up a public institution to our mains where gas lighting had been previously in use, but was being discarded because of insufficient light. In that institution there are about 600 metallic filament lamps and 300 carbon lamps. For the first four months of 1907 the lighting of the institution with gas at 2s. 8d. per 1,000 cub. ft. cost £102, and for the same period of 1908, with vastly improved lighting, the cost with electricity at 4d. per unit was £88. The supply is 110 volts alternating current. I do not agree with the authors in their advocacy of these complicated systems of charging. I take this position on the broad principle that anything which tends to cause a consumer to limit his consumption is bad. The maximum demand system is at fault inasmuch as it does not take into account the time at which the maximum demand is made. In most towns with a mixed power and lighting load we find that for 1½ or 2 hours per day in winter-time the demand at the peak is twice the normal due to overlapping. This peak determines the capital expenditure in the station, and if we can get a customer to keep off at this time it does not matter how much he may demand or how often he may make it. Mr. Robertson.

The contract demand system appears somewhat better, but it is open to objection for the same reason, and any station engineer can easily imagine the difficulties which would be found in fixing the amount of a consumer's contract demand, especially in a small town where every one knows his neighbour's business. The "Norwich" system of charging is a distinct departure and will be watched with interest, but the most perfect method, in my opinion, is the double tariff system; but the time is not far distant, I think, when we will find that a low flat rate with a sliding scale according to quantity will meet all requirements, provided that a minimum charge is made to cover the standing charges on the cost of services and supply meters.

Mr. M. K. Cooper: I am glad to have this opportunity of giving the results of my experience in connection with metallic filament lamps. I agree that in some cases consumers will be able to do with fewer points and thus reduce their consumption. I have had this experience Mr. Cooper.

Mr. Cooper. with our own clients, and they have expressed their great satisfaction. Upon looking into the matter, I find that the supply station suffers very little thereby, and in some cases not at all. For instance, a leading warehouse in town has had on one flat forty-eight 8-c.p. carbon lamps, which equal approximately 1,538 watts and 384 c.p. I have fixed up twenty-four 32-c.p. metallic filament lamps, equal approximately to 1,360 watts and 788 c.p. in all, that is an increase of about 400 c.p. and a decrease of 170 watts. This customer was so highly satisfied with the result that he added other six lamps in different parts of the warehouse, and he would not have done so had he not used the metallic filament lamps.

As a matter of fact I can only agree with the authors on one point, and that is the life of the lamp, which is a very important factor. I have seen in some cases the lamp going in a very short time, say within 50–100 hours.

Comparing this country with others, I find that in Great Britain the charges for current are very high. I have been in the trade since 1895 in three different countries—Germany, Russia, and Austria—and I have never received such serious complaints as from the consumers of this country. The authors of the present paper prophesy that if the increase of metallic filament lamps comes about—which I have no doubt it will—it will not so much affect the large companies in the manufacturing centres (as they have a great power load, and do not depend so much on lighting), but it will prove most serious to the majority of stations in residential districts which depend almost entirely on a lighting load. What steps are the supply stations going to take to meet it? One step, I think, might be taken, and that is the adoption of the Continental system of wiring. I have carried out a great many installations in Germany, Austria, and Russia, and when I inspected one of these last year in a small residental town near Frankfort-on-the-Main, and another in South Russia, I found them in perfect working order, and there were no complaints. The population of the town in question is about 32,000, and while the supply station was in process of erection between the years 1900–1901, there were about 1,500 consumers only, with installations varying from 6 to 250 lamps; and whilst I was there last year during the month of August, I found there were about 2,350 consumers. What is the cause of this? Because wiring is done at such a moderate price, about 6s. per point, including ordinary pendants.

It seems to me that their system of wiring should be adopted in this country, in a modified form at least, and it would open—in my opinion—a great field for every one concerned—maufacturer, contractor, and supply station undertakers. I sincerely hope that there will be no fear for high-efficiency lamps, and that electricity will ere long compete more effectively with gas. This system and the high-efficiency lamp will—through time—lead to a great increase of consumers.

The Chairman. The CHAIRMAN (Professor F. G. Baily): I agree with Mr. Robertson that the demand system of charging is not a sound one, inasmuch as it

does not distinguish between a man whose demand coincides with the station peak and a man whose demand occurs during a period of light load. To make a fair charge the meters should be governed so as to record slowly when the station load is light, and rapidly during the peak, and discounts should be allowed to large consumers, in consequence of the smaller proportional cost of connection, meters, clerking, and collecting. There is no need to distinguish between power, heating and lighting, for it makes no difference to the central station what kind of demand a consumer makes, intermittent or regular, large or small, within reason, so long as his demand keeps off the peak, for the multitude of small fluctuations will produce a fairly steady outflow of current and load on the boilers. That is, I believe, the logical system of charging, to a first approximation of accuracy; but I am quite willing to admit that it may not be the best method from the commercial point of view, where the keenness of the price in a particular line depends on the competition. The Chairman.

Mr. WILLIAM SILLERY (*communicated*): The advent of the metallic filament lamp, in my opinion, is one of the most advanced steps in the supply of electricity during the last fifteen or twenty years. Further, all interested in electrical undertakings have devotedly wished for such a weapon to combat other rival systems of lighting. In the past too much attention has been given to complicated devices between consumers supply and the station, and all sorts of means and instruments were introduced that resulted in the drawback of keeping would-be consumers from coming on the mains. I am of opinion a universal flat rate should be adopted with no distinction as to what purpose current may be used for. Mr. Sillery.

Mr. HANDCOCK and Mr. DYKES (*in reply*): Tariff Reform is a difficult subject, even if it is only in the electrical world, and we are therefore not surprised that very diverse opinions have been taken of the points raised in our paper. In replying to the discussion, we should like to treat first the effect of the metallic filament lamps on the station output if the rates be kept as at present. Mr. Handcock and Mr. Dykes.

We have been surprised to find that everybody has thought we are pessimistic with regard to the effect of the advent of that lamp. We are not at all pessimistic. All we do say is that to get the full advantage of the lamp, the price of the current should be slightly raised in the case of those stations which will be undoubtedly badly affected. There is room to raise the price, and still for the consumer to make a big saving. We do not see why any station should make a loss for want of a little courage in raising the price somewhat now. Mr. Wright says we must induce people to use three times the amount of light and keep their consumption the same—a delightful solution to the problem—but how can one do it? People do not greatly increase their light, but they do reduce their consumption. Probably every member could bring forward instances of this, and many, particularly those in charge of alternating-current stations supplying residential districts, can point to the mournful fact that their output

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has fallen considerably below what it was a year or two ago. It is true that direct-current stations have so far not suffered to anything like the same degree as the alternating-current stations, but the "shunt" lamp shown by Mr. Stearn (and for which, as that gentleman remarked, we fear that we are responsible) will bring many possibilities in the way of economy, within reach of the direct-current consumer, which were previously only available to consumers on alternating-current circuits. Mr. Tapper, of the Beckenham Electricity Works, seems to us to have put the case, as it affects a certain class of station, in a nutshell.

We may mention the case of a certain well-known alternating-current station, the name of which, for obvious reasons, we withhold. During the last three years the number of consumers and the lamp connections have increased with satisfactory regularity, and up to last summer the output increased in an equally gratifying manner. During last autumn the district was invaded by the new metallic filament lamps, with the result that the station output has gradually fallen, until at the present time it is well below what it was two years ago.

Certain electrical journals and several members who took part in the discussion, apparently advise the engineers in charge of those stations not to be troubled, but to wait patiently, and in a few years time the increase in the number of consumers will more than repay them for the temporary diminution in their receipts. Mr. Hirst, with his well known business ability, saw clearly from the beginning that the effect on the stations might be serious to commence with, and personally we regard it as a great pity that the offer which he made to the station engineers was not accepted. He, nevertheless, is one of those who strongly urges that station engineers should do nothing.

Let us consider the position for a moment. For lamp makers the conditions have altered, and they find themselves in possession of a lamp which gives three times the light for the same amount of current. At the same time the station engineer finds the conditions changed, and his current is able to give three times the amount of light that it did formerly. Their advice to the station engineer is to continue to sell his current at the same price, and cheerfully endure the loss for a longer or shorter period, in the hope that eventually he will recoup himself. It is to be expected, therefore, that the lamp makers would sell the new lamps at the same price as the old, and trust to the increased sales to repay them. Is this what has happened? No! They charge for the new lamps four times as much as for the old, but promise that as the sales increase and they find themselves in a position to do so, they will lower the price. We think the station engineer will do well to follow their practice.

Again, if it be true that the effect of these lamps, giving three times the amount of light for the same current, will be to induce such a rush of customers as to more than repay the station engineers for their initial loss, surely the same result might have been obtained in the

days of carbon lamps by boldly reducing the price of current to one-half. Mr. Handcock and Mr. Dykes.

Mr. Wright states that if the output of the Marylebone Station were doubled, the cost would probably come down from 4½d. to 2½d. Surely, then, if our critics are right, what he should have done a year or two ago was to reduce his price from 4½d. to 2½d., when the increase in new consumers would have more than recouped the loss. He did not do so, however. Both he and Mr. Bottomley Smith are well aware of the service difficulty, and they both hope that it will be overcome in the future, but that day is not yet; and meantime we think it may be taken that the discussion has endorsed our view that if matters are left as they are, the stations will be, for a longer or shorter period, badly affected. Capital is at the present time very nervous, and local authorities hesitate before expending money on electrical plant. The effect of a cessation of dividends or a call on the rates, even if only for a short time, would be far reaching and would greatly affect every section of the electrical industry.

In the light of the fact that a consumer, using the new lamps, could be charged as high as an average of 1s. 2d. per unit without affecting his total lighting bill, what possible reason is there for the industry incurring a loss when it can be avoided by a slight adjustment of price?

Given that a readjustment is necessary, on what basis shall it proceed? Since our paper was written, we have been gratified to find that many others, who have given thought and attention to the subject, have arrived at practically the same conclusions as ourselves. Mr. Long is one of these and he has explained his method on carrying it into effect. His system, as far as it relates to business premises, is practically the same as our own, with the exception that he does not use limit indicators, and relies for carrying it into effect on his knowledge of every consumer's load factor and maximum demand, the latter obtained apparently by maintaining their lamps. He supplies two valuable facts:—

First, that the consumers easily understand the system, and do not object to it, thus answering Mr. Smith.

Secondly, that the consumption per lamp increases.

Mr. Bowden refers to an article by himself and Mr. Tate, in which, without of course having metallic filament lamps in mind, he came to the same conclusions as ourselves, namely, that consumers should be charged a rental depending on their demand on the station and in addition a meter charge to cover the running costs. After careful analysis of the Poplar accounts, they constructed a table showing that at that time the consumer who used his lights on the average of only a quarter of an hour per day cost the station 28·00d.; the one-hour consumer, 7·35d.; the six-hour consumer, 1·60d.; and the twenty-four-hour consumer, 0·74d.; or, in other words, that the short-hour consumers were a dead loss to the station, even if charged the full 8d. per unit. If this is true in the case of a large metropolitan station, it will be still more true in the case of a rural or suburban station.

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What possible justification can there be under these circumstances for charging a flat rate, and for the legislature, by retaining the 8d. limit, to cause the station to charge a man who should only pay 0.74d. per unit, four or five times as much, simply in order that a number of other consumers should have their current at far below cost price? This may carry out the letter of the Act, but it certainly does not correctly interpret the views of the framers of that Act.

Engineers generally being agreed upon the principle of charging, the question remains as to the best method of carrying it into effect. Is the system which we suggested the best way to do so? What are the criticisms?

Mr. Bowden states that the whole paper "is based upon a misconception of the fundamental principle of equitable charging." To prove this point, he takes the following figures relating to the Poplar Station.

He estimates that during the year the figures will be:—

	Maximum Load on Station.	Units Consumed.	Price per Unit Charged.	Total Revenue.
	Kilowatts.		d.	£
Power	1,700	4¼ millions	1·05	18,593
Private lighting	1,000	1 ,,	3·43	14,291
Public lighting	200	¾ ,,	1·50	4,687

He then attempted to apply our system to these figures, but, unfortunately, made two mistakes. The first is, that he has added all his expected profit on to the rental charge, and the second, that he has charged the consumers on the capacity of plant or lights installed instead of on their contract demand. The effect of this, of course, would be the same as the original Hopkinson method—to reduce the lights installed. All that concerns the station is the demand the consumer elects to make on it.

We agree, nevertheless, that the effect of our system on his figures would be to increase somewhat the charge for power and reduce it for private lighting. This, Mr. Bowden considers absolutely wrong, but let us for a moment consider his figures.

His revenue from 1,700 k.w. power demand is £18,593 per annum, or in other words, he gets £10·94 per kilowatt of demand on the station for which he supplies 2,500 units per kilowatt, which is equivalent to running his plant for 2,500 hours per annum. From the 1,000 k.w. of private lighting demand he receives a revenue of £14,291, or £14·3 per kilowatt of demand on the station for which he supplies 1,000 units per kilowatt equivalent to running his plant for 1,000 hours, and for public lighting £23·43 per kilowatt of demand for 3,750 hours.

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Thus the lighting consumer pays nearly 40 per cent. more per kilowatt of demand on the station than the power consumer, although the latter uses the plant 2½ times as long. It is further clear that public lighting is also penalised to subsidise the power consumer. This is clearly not "equitable charging," although we do not deny that in certain cases it may be good business policy to encourage the use of current for power purposes.

Mr. Wright also points out that the current for power should be supplied at less cost than for lighting owing to its greater diversity factor. Our system, as proposed, goes a long way towards meeting this, and can, and should be made to do so absolutely.

If a consumer has lamps connected of a total capacity of 100 k.w., he will probably put his contract demand at 70 k.w. If he has motors of an aggregate capacity of 100 k.w., owing to the greater diversity factor, he would probably put his contract demand at 35 k.w. In the first case, therefore, his rental charge would be double what it would be in the second. This, however, like the maximum demand system, is not quite fair to the consumer with only one meter, as his diversity factor in that case would be unity.

It is well known that if a demand indicator is put in a works with ten 1-H.P. motors, and that if demand indicators are put in ten works each with one motor, the revenue derived from the ten installations with one motor each will be considerably greater than that derived from the works with ten motors.

The point, however, is easily met by charging power consumers a lower rental per kilowatt of contract demand and public lighting a somewhat higher one than lighting consumers, the exact difference depending on the ratio between their diversity factors and the proportion which each bears to the total demand on the station.

To show how this works, we take Mr. Bowden's figures, which are very interesting—our own used in preparing the paper being for stations supplying practically private lighting only, these being the ones most affected by the lamps.

The total revenue is £37,571, of which £4,000, or just over 10 per cent., is profit. He sells six million units which, at 0·45d. (his estimated running costs) plus 10 per cent. for profit, equals £12,375.

His standing charges, including 10 per cent. profit, are £24,200. It is clear that this amount must be allocated amongst the three classes of consumers in proportion to their maximum demand on the station. (This assumes, as would be approximately the case, that the demands coincide.)

Power should pay $\frac{14}{20}$ of £24,200
= £14,180 + 4½ million units at 0·495d. = £22,945.

Private Lighting should pay $\frac{5}{20}$ of £24,200
= £8,344 + 1 million units at 0·495d. = £10,406.

Public Lighting should pay $\frac{1}{20}$ of £24,200
= £1,669 + ⅓ million units at 0·495d. = £3,218.

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Having thus calculated the total amounts to be obtained from each of the three classes of consumers, it only remains to allocate it amongst the individual members of each in proportion to their contract demands. What proportion these will bear to the maximum demand on the station can only be arrived at by one familiar with the district and the individual consumers.

We assume that the 1,700-k.w. maximum power demand on the station, derived from 6,370 k.w. installed, would give 3,685 k.w. of contract demand; 1,000 k.w. private lighting, 2,500 k.w. installed, 1,500 k.w. of contract demand; 200 k.w. public lighting, 200 k.w. installed, 200 k.w. of contract demand.

This would bring out the charges for the three classes :—

Power £3·84 per k.w. contract demand and 0·495d. per unit.
Private lighting £5·56 „ „ „ 0·495d. „
Public lighting £8·30 „ „ „ 0·495d. „

For comparison, we put these figures beside Mr. Bowden's.

	Mr. Bowden's.		Handcock & Dykes.		
	Total Revenue.	Average per Unit.	Total Revenue.	Average per Unit.	Rent per Kilowatt Contract Demand.
	£	d.	£	d.	£
Power	18,593	1·05	22,945	1·290	3 84
Private Lighting...	14,291	3·43	10,406	2·490	5·56
Public Lighting ...	4,687	1·50	3,218	1·027	8·30

At first sight some may be surprised that the rental per kilowatt for public lighting should be more than for power or private lighting. The reason is, of course, that owing to the long hours and unity diversity factor of public lighting load a portion of the plant is practically reserved entirely for it.

Mr. Rawlings raises a very practical point as to what would happen, say in a West-End house, where they occasionally want a temporary extension of their installation for an entertainment. This would be met by a special charge for the evening being made. The amount of this charge would obviously depend on the time of year and whether the plant of the station was fully loaded or not, and would easily be arranged by the engineer in charge of the station.

We cannot quite follow the argument used by Mr. Mordey that if a party is given in one house, there are less lights used in the others. This would seem to imply that while a man's daughters were at a dance the rest of the family sat at home in the dark. In practice it must mean a somewhat larger load on the mains, although of course in

a large district the effect of any individual entertainment would scarcely be felt. In actual practice, small country stations repeatedly find that entertainments simultaneously at one or two large consumers premises do increase the station load, and therefore must lead to a larger reserve of plant being installed than would otherwise be necessary. Mr. Handcock and Mr. Dykes.

Mr. Still, while apparently liking the system, is afraid of the difficulty in working, and anticipated trouble in fixing what a large consumer's contract demand was. The underlying principle of the system is that there is no need for the station to fix the contract demand. In practice the system would probably be worked as follows :—

On a new consumer being connected, the supply station representative, after inspecting the premises and getting an idea of what the number of lights would be, would ask the consumer how many lights he would be likely to want to burn at once, a question which with a little assistance from the engineer, few consumers would have any difficulty in settling. He would then say, "We shall put you in a meter which will give you current up to this amount, and for the facility you will be charged a fixed rental per annum, divided into four quarterly instalments of so much, and in addition, all the current you use will be charged at, say, 1d. per unit." It would be pointed out to the consumer that the charge for current would only amount to a small sum, and that therefore there would be no necessity to be always troubling to turn off the lights, as is done at the present time, and that within a little he would know what his bill was going to be.

Probably in nine cases out of ten this would end the matter, but in the remaining case the consumer would find that after a few days or weeks he was exceeding his demand and the lights were becoming dimmed. He would inform the station of this, when they would point out to him that he was obviously using more lights than he anticipated when he made arrangements with the company, and that he could either keep to his original price by switching off some of his lamps, or could have the capacity of his meter increased (there is no need to confuse him with the words "limit indicator" at all), when he would have to pay a somewhat higher rental.

The accounts would be simplicity itself. A rental charge depending on the capacity of the meter (that is, of course, on the setting of the "limit indicator") and 1d. per unit for all current, whether for basement or bedroom lighting or for a radiator.

If the current were entirely for lighting, the rental would be somewhat higher than if for power. Surely this meets the demand emphasised by several speakers for a simple system of charging.

If one tells a new customer, who knows nothing of electricity, that he will be charged at a flat rate of 3d. per unit, he has not the faintest idea as to what his bill is likely to be, and many people will not come on to the mains for this reason.

With the contract demand system, however, the station engineer

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can, in most cases, form a pretty accurate idea as to what the contract demand is likely to be, and with that information he can tell the customer, straight away, very closely what the bill for lighting will amount to.

Incidentally, the system has one very great advantage in that it would tend to equalise the accounts for the four quarters of the year. Consumers always grumble when they get a heavy winter-quarter's bill, but are apt to overlook the fact that they have had a correspondingly light bill in the summer quarter.

In the case of continuous-current stations, the indicator for a lighting load consists of a small form of cut-in and cut-out, which, when the current exceeds a predetermined limit, operates and throws a resistance in and out of circuit, thus causing the whole of the lights to jump up and down in a most irritating manner. In alternating-current stations a small choking coil takes the place of the resistance. On the lamps which are lighted, being reduced to the normal number, the indicator ceases to operate and the lighting becomes normal again.

On power loads we prefer to use a form of maximum demand indicator having a considerable time lag, together with a bell which starts ringing when the limit is exceeded. The consumer can then either reduce the load, or, if this is not done within the period taken by the demand indicator to record the excess of current, the actual demand as shown on the demand indicator will be taken as his "contract demand" and the rental adjusted accordingly. The object in introducing a considerable time lag is to avoid penalising consumers for a momentary overload, and to ensure the carrying out of the underlying principle of our system, namely, that the consumer's demand is under his own control, and he cannot be called upon, as in the maximum demand system, to pay an increased bill without his being in advance fully conversant of the liability which he was incurring.

A complaint is often made against electrically lit houses that, owing to passage and bedroom lights, etc., being immediately switched off when not actually required, the houses look dark. Again, people often use gas for kitchens and passages and other long-hour lights, and keep electricity for the short-hour lights.

This state of affairs, which is absurd in the light of the figures given in our paper as to the relative capitalisation of gas and electricity undertakings, has been brought about entirely by the use of the flat rate.

Once the contract demand system is adopted it makes very little difference in the annual bills if such lights be used for double the length of time, a result which will go very far to make electric lighting popular. This effect is clearly borne out by Mr. Long's results.

This system can, of course, be adopted without increasing the average price at all, if it is not considered that an increase is necessary. Consumers can be given the option of being charged on this system or on the maximum flat rate provided in the schedule of that particular order.

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In many districts it will probably be found advisable boldly to recommend all consumers to use the new lamps, pointing out to them the saving to be effected, and adjusting the rental charge to such a figure as will give an increased return per unit, sufficient to counteract the falling off in the demand of individual consumers.

Although this will meet the position in most cases, we are strongly of opinion that the inequality of the present legal flat rate should be brought before the authorities. The Board of Trade, we have reason to believe, will consider sympathetically any representations made by this Institution.

We are not of opinion that it will be necessary to raise the average price above the present statutory limit, but are firmly convinced that we should have powers to charge unprofitable short-hour consumers more than they are at present paying in order to reduce the price to the more remunerative long-hour consumers, and thus compete with other illuminants on a more logical and at the same time more remunerative basis.

Obviously there are many points better discussed in private, and we venture therefore to suggest that the Institution should call together a committee of those most interested in the matter, to consider if joint action is advisable, and if so, to formulate proposals.

It is very interesting to hear Mr. Lackie's views on our paper, but he has one great advantage over us, as we are responsible for several stations which supply almost entirely a residential load, and, unfortunately, these stations cannot supply a power at the extremely low price that is done in Glasgow, and there is not so much inducement to put in such lamps as in Glasgow. We take comfort from the fact, too, that the tendency has been to use more illumination and not to reduce the account for current. That is quite right so long as we have to put twenty or thirty lamps in series, but it is a different thing when we can put in a transformer and use a lamp taking 10 watts, as one can do with the new lamp with the continuous current. One does not want to use a glaring light at home, and we are not going to put in a light that would ruin our eyes more than ever. Mr. Lackie's idea is to charge so much per kilowatt installed and nothing else, and that is the simplest way of all, but we do not believe in charging it per kilowatt installed, because that tends to make a man reduce his light, and the question is, How many can he put on at once? If one does not make some small charge there is a tendency to waste, and one might as well make a little charge. Mr. Robertson is also in the position of having a large power load; but there is one point that Mr. Robertson touched on, namely, the fact that the gas companies cannot reduce their price very much. There is no margin for them on their capital cost. We have seriously considered the matter in one or two towns where we have strenuous competition with gas, and where one can afford for a year or two to make a loss and drop the price right down. We can cut the ground right from under the gas company, but we cannot go on reducing it. The cost is in making the gas, therefore

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they cannot go down below a certain price, whereas electrical companies can afford to set aside for a year or two their interest on their capital, and can afford to run the gas company off the field and then be able to raise the price. Mr. Cooper makes a very good suggestion, that the consumers want a little instruction as to the handling of filament lamps. When one gets a filament lamp into its place it will stand a good deal of vibration, but if it is dropped suddenly, being very brittle, it usually breaks. As to Professor Baily's remarks about improving the load factor, we must confess, with all due deference, that we do not know how we are going to do so, unless we go on in the old way.

At each meeting at which the paper was read a cordial vote of thanks was passed to the authors for their valuable communication.

Proceedings of the Four Hundred and Seventy-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held at the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, Westminster, on Thursday evening, April 23, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on April 9, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members :—

John M. Harvard. | Henry B. Swift.

From the class of Students to that of Associate Members :—

Philip P. Sandford.

Messrs. L. Gaster and R. B. Matthews were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Member.

Charles Douglas Burnet.

As Associate Members.

Frank Steadman Collings. | Archibald R. Low.
Isaac Dalmer. | Leonard Oulton.
John Herbert Fossett. | William E. Shuttleworth.

Reginald Chalmers Hammond, Captain, R.E.

As Associates.

George Basil Barham. | Edgar Thomas Larner.
Vincent Ignatius Stephens.

As Students.

Arthur Roy Alderson.	Benjamin Frederick Hill.
Cyril George Dickinson.	Robert Douglas Norman.
John Horncastle Eddison.	John Stephen.

The discussion on the paper by Mr. H. W. Handcock and Mr. A. H. Dykes was concluded (see page 355).

Proceedings of the Four Hundred and Seventy-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 30, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on April 23, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

William George Murrin.

From the class of Associates to that of Associate Members :—

Newell Hosgood.

From the class of Students to that of Associate Members :—

H. T. G. Edmonds.	George W. Kidd.
Walter J. Jeffery.	Henry S. Poole.

The SECRETARY read the following list of Council nominations for election to the Council for the ensuing session :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE 1908–09.

As President.

Nomination — W. M. MORDEY.

As Vice-Presidents.

Remaining in Office — COL. H. C. L. HOLDEN, R.A., F.R.S.; DR. G. KAPP.

New Nominations — F. GILL.; C. P. SPARKS.

As Ordinary Members of Council.

Remaining in Office	S. EVERSHED. H. E. HARRISON. DR. E. HOPKINSON. J. W. JACOMB-HOOD. J. E. KINGSBURY. M. O'GORMAN. G. W. PARTRIDGE. W. H. PATCHELL. W. RUTHERFORD. A. A. C. SWINTON.
New Nominations	T. MATHER, F.R.S. MAJOR W. A. J. O'MEARA, C.M.G. PROF. A. SCHWARTZ. J. F. C. SNELL. G. STONEY.

As Associate Members of Council.

Remaining in Office	J. HUNTER GRAY. H. HUMAN.
New Nomination	J. E. TAYLOR.

As Honorary Treasurer.

For Re-election	ROBERT HAMMOND.

As Honorary Auditors.

For Re-election	H. ALABASTER. SIDNEY SHARP.

The PRESIDENT: This list has been prepared in accordance with Article 45 of the Articles of Association, and it is open to any member to add other names to the list after getting the consent of his nominees to act, if elected.

PRESENTATION OF A BUST OF BENJAMIN FRANKLIN BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The President.

The PRESIDENT: I understand we have among us an ambassador from the American Institute of Electrical Engineers, who is charged with the performance of a certain duty, and I now have pleasure in calling upon him to perform it.

Mr. Parshall.

Mr. H. F. PARSHALL: Mr. President and Members of the Institution of Electrical Engineers,—I have the honour and pleasure to present on behalf of the American Institute of Electrical Engineers a souvenir of their happy remembrances of a trip to this island about a year and a half ago. They were so cordially received by the

members of this Institution that a lasting impression was made upon their minds, hence the desire particularly to emphasise in a permanent way their appreciation of the kindness and hospitality which they received at the hands of their brother engineers in Great Britain. Although the number of members of the American Institute that were able to come abroad was but a small fraction of the whole, the account they gave of their reception was so cordially received by the Institute as a whole that this tribute comes forward by the unanimous wish of the members of the American Institute. It may not be generally known that this presentation would have been made on the inauguration of Lord Kelvin as President of this Institution. This was thought to be the most auspicious occasion that could be selected to emphasise the friendship which exists between the two institutions; in fact, it was felt that this was the most auspicious occasion that could happen in the electrical engineering world, since nothing could so far advance the position of the electrical engineer as the fact that Lord Kelvin at his great age and with his great position was willing to preside over this Institution as an expression of his desire to further the interests of electrical engineering. Alas! the occasion so much hoped for was not to be. It is consoling, however, to think that Lord Kelvin, accompanied by Lady Kelvin, had seen this statue and had expressed his appreciation and admiration for it, and it certainly adds greatly to the value of it to know that he strongly approved of the sentiment by which the gift was prompted. The letter from Mr. Pope, Secretary of the American Institute, asking me to make this presentation, stated that the subject was Benjamin Franklin. It appeared to me that the selection was an extremely happy one, since America can claim Benjamin Franklin by common consent as her greatest natural philosopher. Kelvin, as we are all most happy and proud to admit, was the greatest natural philosopher and scientist associated with the advancement of electrical science yet born to the world. Franklin's insight into nature came from a purely natural genius, and the discoveries he made were intuitive. Kelvin had the same natural genius, but he had the additional advantage of great mathematical powers of analysis. While the investigation of electrical phenomena by Franklin was but one department of a busy life, and became more of a pastime given out of such time as could be spared from attending to matters of state, since he was perhaps greater as a statesman than as a natural philosopher, Kelvin's whole life was devoted to science, and without intermission he successively enriched and perfected knowledge in all branches of physical science. It has been frequently stated that for all practical purposes Franklin was an Englishman. That his origin and methods were English there can be no dispute nor wish to dispute so far as the Institution I am speaking for is concerned, and this same characteristic applies to most of the names that have given America her position in connection with the development of electrical science. I refer to such names as Henry, Farmer, Morse, Bell, Edison, and Elihu Thomson. It is with especial pleasure that I make this presentation, since I have the honour of being a Member of both

Mr. Parshall.

Mr. Parshall.

the American and British Institutions, and having now resided so many years in this country, any event that may emphasise and strengthen the friendship between the two leading bodies of electrical engineers is especially welcome to me. Mr. President and Members of the Institution of Electrical Engineers, I now respectfully request you to accept this bust of Benjamin Franklin as a token of the sincere friendship and esteem of your brother engineers in America, the President and Members of the American Institute of Electrical Engineers.

The President.

The PRESIDENT: Mr. Parshall, and other Members of the American Institute of Electrical Engineers who are present,—On behalf of the Council and the members of our Institution, I wish to say that we very highly appreciate this beautiful gift to us from our American friends, in courteous recognition of their reception and entertainment on the memorable occasion when it was our great privilege to receive them as the honoured guests of the Institution. I have also to thank you, Mr. Parshall, for the appropriate and kindly words you have used in referring to our late President, Lord Kelvin. I understand from what you have said that both he and Lady Kelvin saw and greatly admired the bust of Benjamin Franklin which you have now presented to the Institution, and we deeply deplore the sad event which prevented the acceptance of the bust by him as our President at the opening of the session. It now remains for me to accept with gratitude, in the name of our members, this representation of your illustrious countryman, that great investigator and statesman Benjamin Franklin. I beg that you will bear to your President and members in America a message from us expressive of the warm feeling which we have for them, and tell them that we shall ever entertain the liveliest recollection of their kindly reception of us when we visited the United States, at the time of the St. Louis Exhibition in 1904. We feel we were only able to make but a poor return to them when they honoured us, two years ago, by becoming our guests in turn; but we hope we may be able to receive them again at some future time, and that there will be many opportunities of fostering the cordial relationship and warm feeling which exist between the two Institutions, making them practically one as regards scientific thought and attainment. The gift of to-day forms an additional tie between our two great kindred Societies.

I have now to propose that the most cordial thanks of the Institution of Electrical Engineers be, and are hereby, expressed to the American Institute of Electrical Engineers for their great kindness and courtesy in presenting to us, through Mr. H. F. Parshall, their Hon. Secretary for Great Britain, the magnificent bust of their great countryman and pioneer investigator in electrical science, Benjamin Franklin. The gift will ever be treasured and preserved in token of the cordial friendship existing between the sister Electrical Engineering Societies of America and Great Britain.

The resolution was carried with acclamation.

Dr. Silvanus P. Thompson, F.R.S., Past President, then delivered his Kelvin Lecture :—

THE KELVIN LECTURE.

THE LIFE AND WORK OF LORD KELVIN.

By Professor SILVANUS P. THOMPSON, D.Sc., F.R.S., Past President.

(*Delivered April* 30, 1908.)

ON the 17th of December, 1907, aged eighty-three years, died William Thomson, Baron Kelvin of Largs, President, for the third time, of the Institution of Electrical Engineers.

Adequately to set forth the life and work of a man who so early won and who for so long maintained a foremost place in the ranks of science were a task that is frankly impossible. The greatness of a man of such commanding abilities and such profound influence cannot rightly be gauged by his contemporaries, however intimately they may have known him. We of the present day are so essentially products of our generation, and have been brought up in modes of thought so largely moulded by him, that we cannot adequately realise how much of that which is familiar and commonplace to us is due to his genius. Whatever our appreciation of present scientific knowledge in the domain of natural philosophy, in which he was for more than half a century pre-eminent over all others, we realise only with difficulty and imperfectly the prior state of things, and therefore cannot clearly discern how much of scientific progress is attributable directly to him. But if by the very circumstance that we have lived so near to him we are debarred from rightly estimating his greatness, we at least have the advantage over posterity that we have been able to speak with him face to face, to learn at first hand his modes of thought, to sit at his feet as students or disciples, to marvel at his strokes of genius achieved before our very eyes, to learn to love him for his single-hearted enthusiasms, for his kindliness of soul, his unaffected simplicity of life.

But if we may not attempt the impossible, we may at least essay the task of setting down in simple fashion some account of those things which he achieved in the science and the profession represented by this Institution of Electrical Engineers.

Let me first set down in briefest outline a sketch of his early life.

William Thomson was born on June 26, 1824, in Belfast, being the second son and fourth child of James and Margaret Thomson. James

Thomson, who was at that time Professor of Mathematics in the Royal Academic Institute of Belfast, was the son of a small farmer at Ballynahinch, in County Down, where his ancestors had settled about the year 1641 when they migrated from the lowlands of Scotland. James Thomson had early shown a taste for mathematical studies, and by study of books had mastered the art of making sundials. He had then been sent to a small school in the district to learn classics and mathematics, rising while still a youth to the position of assistant teacher. During the winters he followed the courses in the University of Glasgow, crossing back to Belfast for the summers to resume teaching at school. After thus attending Glasgow University for five years he was appointed Professor of Mathematics in 1815 at the Belfast Academic Institute. His eldest son, James (Lord Kelvin's elder brother), was born in 1822, and William (Lord Kelvin), as already stated, in 1824. In 1830, when William was six years old, his mother died. His father would never send his boys to school, but taught them himself. In 1832, when William was eight years old, Professor Thomson was offered the Chair of Mathematics at Glasgow, and he with his family of six children accordingly removed from Belfast. He was in many ways a remarkable man. He made several original contributions to mathematics, and produced several sound text-books, including one on the Differential and Integral Calculus. But his range of accomplishments was wide. He was an excellent classical scholar, familiar with both Latin and Greek, and able, on occasion, to give lectures in the Classics to the University students. After his removal to Glasgow he still kept the education of his sons in his own hands, and so it happened that in 1834 William Thomson, when in his eleventh year, matriculated as a student in the University without ever having been at school. He early made his mark by his progress in Mathematics and Physical Science, and in 1840 produced an essay "On the Figure of the Earth," which won him the University Medal. He also read Greek plays with Lushington, and Moral Philosophy. To the end of his life he was in the habit of bringing out quotations from the classic authors. His fifth year as a student at Glasgow, 1839–40, was notable for the impulse toward Physics which he received from the lectures of Professor J. P. Nichol and from those of David Thomson (a relation of Faraday), who temporarily took the classes in Natural Philosophy during the illness of Professor Meikleham. In this year William Thomson had systematically studied the "Mécanique Analytique" of Lagrange and the "Mécanique Celeste" of Laplace, both mathematical works of a high order, and had made the acquaintance—a notable event in his career—of that remarkable book, Fourier's "Théorie de la Chaleur." On May 1st he borrowed it from the College Library. In a fortnight he had read it completely through. The effect of reading Fourier dominated his whole career thenceforward. He took the book with him for further study during a three months' visit to Germany. During his last year (1840–41) at Glasgow he communicated to the short-lived *Cambridge Mathematical Journal*, under the signature

"P. Q. R.," an original paper, "On Fourier's Expansions of Functions in Trigonometrical Series," which was a defence of Fourier's deductions against some strictures of Professor Kelland. He left Glasgow University after six years of study, without even taking his degree, and on April 6, 1841, entered as a student at St. Peter's College, Cambridge. Here he speedily made his mark, and continued to contribute—at first anonymously—to the *Cambridge and Dublin Mathematical Journal*, papers inspired by his study of the higher mathematics and by his love for physics. The analogy between the movement of heat in conductors along lines of flow and across surfaces of equal temperature, and the distribution of electricity on conductors in such a way that the lines of electric force were crossed orthogonally by surfaces of equipotential, led to his paper entitled "The Uniform Motion of Heat in Homogeneous Solid Bodies, and its Connexion with the Mathematical Theory of Electricity." Here was an undergraduate of seventeen handling methods of difficult integration readily and with mastery, at an age when most mathematical students are being assiduously drilled in so-called geometrical conics and other dull and foolish devices for calculus-dodging. It is true he followed the courses of coaching prescribed by his tutor Hopkins, but he could not be kept to the routine of book-work, and he never quite forgave Hopkins for keeping from him until the last day of his residence at Cambridge, Green's rare and remarkable "Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism." He also formed a close friendship with Stokes, then a young tutor, with whom, until his death in 1902, he maintained a continual interchange of ideas and suggestions in mathematical physics. Of Thomson's Cambridge career so much has been written of late that it may be very briefly touched here. How he went up for his Tripos in 1845; how he came out Second Wrangler only, being beaten by the rapid Parkinson; how he beat Parkinson in the Smith's Prize competition; how he rowed for his College to save Peterhouse from being bumped by Caius; how he rowed for Cambridge in the University race of 1844; how he won the Colquohoun silver sculls; how he helped to found the Cambridge University Musical Society, and played the French horn in the little orchestra, which at its first concert on December 8, 1843, performed Haydn's *First Symphony*, the Overture to *Masaniello*, the Overture to *Semiramide*, the *Royal Irish* Quadrilles, and the *Elizabethen* Waltzes of Strauss! But these things, are they not written in the book of the *Cambridge Chronicle*?

Once when Lord Kelvin was in a chatty mood I asked him point-blank how it occurred that he was not Senior Wrangler. His blue eyes lighted up as he proceeded to explain that Parkinson had won principally on the exercises of the first two days, which were devoted to text-book work rather than to problems requiring analytical investigation. And then he added, almost ruefully, "I might have made up on the last two days but for my bad generalship. One paper was really a paper that I ought to have walked through, but I did very badly by my bad generalship, and must have got hardly any marks. I spent nearly

all the time on one particular problem that interested me, about a spinning top being let fall on to a rigid plane; a very simple problem if I had tackled it in the right way, but I got involved and lost time on it and wrote something that was not good, and there was no time left for the other questions. I could have walked over the paper. A very good man Parkinson—I didn't know him personally at the time—who had devoted himself to learning how to answer well in examinations, while I had had, during previous months, my head in some other subjects not much examined upon—theory of heat, flow of heat between isothermal surfaces, dependence of flow on previous state, and all the things I was learning from Fourier." And then he drifted off into a talk of his early papers, and to the mathematical inference (as the result of assigning negative values to the time t) that there must have been a creation. "It was," he continued, "this argument from Fourier that made me think that there must have been a beginning. All mathematical continuity points to a beginning—this is why I stick to atoms . . . and they must have been small—smallness is a necessity of the complexity. They may have all been created as they were, complexity and all, as they are now. But we know they have a past. Trace back the past and one comes to a beginning—to a time zero beyond which the values are impossible. It's all in Fourier."

On leaving Cambridge, with a College Fellowship of £200 a year to maintain him, Thomson went to Paris and worked in the laboratory of Regnault at the Collège de France. He was here four months. There was no arrangement for systematic instruction, and Thomson's principal occupation was to work the air-pump to make a vacuum in one of two large glass globes which Regnault was weighing against one another in some determinations of the densities of gases. He made here the acquaintance of Biot and of Sturm and Foucault, of whom he spoke in terms of admiration.

Thomson was now twenty-one years old, but had already established for himself a growing reputation for his mastery of mathematical physics. He had published about a dozen original papers, and had gained experience in three Universities. In 1846 the Chair of Natural Philosophy at Glasgow became vacant by the death of Professor Meikleham, and Thomson, at the age of twenty-two, was chosen to fill it. His father, Professor James Thomson—he died in 1849—still held the Chair of Mathematics, Professor Thomas Thomson held that of Chemistry, while Professor Allen Thomson occupied the Chair of Anatomy. William Thomson was the youngest of the five Professor Thomsons then holding office in Glasgow. He chose for the subject of his inaugural lecture: "On the Distribution of Heat through the Earth."

This Professorship he continued to hold till he resigned it in 1899 after continuous service of fifty-three years. Of his work as a University teacher this is hardly the occasion to say much: it will be fully described by his pupil and successor, Professor Andrew Gray. The old college buildings where he lectured and worked for twenty-four years were ill-adapted for any laboratory facilities, yet he contrived to

organise a physics laboratory—the first of its kind in Great Britain—in some disused rooms in a dark corner of one of the quadrangles, and enlisted the voluntary service of a number of keen students in his early experimental researches on the electrodynamic and thermoelectric properties of matter. In the lecture theatre his manifest enthusiasms won for him the love and respect of all students, even those who were hopelessly unable to follow his frequent flights into the more abstruse realms of mathematical physics.

Over the earnest students of natural philosophy he exercised an influence little short of inspiration, an influence which extended gradually far beyond the bounds of his own University.

The next few years were times of strenuous work, fruitful in results. By the end of 1850, when he was twenty-six years of age, he had published no fewer than fifty original papers, mostly highly mathematical in character, and several of them in French. Amongst these researches there is a remarkable group which originated in his attendance in 1847 at the meeting of the British Association. He had prepared for reading at that meeting a paper on the exceedingly elegant process discovered by himself of treating certain problems of electrostatics by the method of electric images, a method even now not sufficiently well appreciated. But a more important event was the commencement of his friendship with Joule, whom he met here for the first time. Joule, a Manchester brewer, and Honorary Secretary of the Manchester Literary and Philosophical Society, had for several years been pursuing his researches on the relations between heat, electricity, and mechanical work. Incited at first by Sturgeon into investigations on the electromagnet, and on the performance of electromagnetic engines—that is electric motors, Joule had already, in 1840, communicated to the Royal Society a paper on the "Production of Heat by Voltaic Electricity." He had also read papers at the British Association's meetings "On the Electric Origin of Chemical Heat," at Manchester, in 1842; "On the Calorific Effects of Magneto-electricity," and "On the Mechanical Value of Heat," at Cork, in 1843; "On Specific Heat," at York, in 1844; and "On the Mechanical Equivalent of Heat," at Cambridge, in 1845. But at that date, when there was as yet no doctrine of Conservation of Energy, when scientific men were not accustomed to distinguish either in language or in fact between force and work, when "caloric" was classed with Light and Sound amongst the "imponderables," Joule's work was listened to with impatience, and his teachings fell upon deaf ears. Was he not an amateur, dabbling in science, and carried away with strange notions? For the Oxford meeting, too, Joule had prepared a paper. Its title was, "On the Mechanical Equivalent of Heat, as Determined from the Heat Evolved by the Agitation of Liquids." It was relegated to an unimportant place, and would have received as little notice as its predecessors but for Thomson's intervention. Joule himself, in 1885, penned the following account[*] of the incident :—

[*] J. P. Joule, "Scientific Papers," vol. ii., p. 215.

"It was in the year 1843 that I read a paper 'On the Calorific Effects of Magneto-Electricity and the Mechanical Value of Heat' to the chemical section of the British Association assembled at Cork. With the exception of some eminent men, among whom I recollect with pride Dr. Apjohn (the President of the Section), the Earl of Rosse, Mr. Eaton Hodgkinson, and others, the subject did not excite much general attention; so that when I brought it forward again at the [Oxford] meeting in 1847 the chairman suggested that as the business of the section pressed, I should not read my paper, but confine myself to a short verbal description of my experiments. This I endeavoured to do, and discussion not being invited, the communication would have passed without comment if a young man had not risen in the section, and by his intelligent observations created a lively interest in the new theory. The young man was William Thomson, who had two years previously passed the University of Cambridge with the highest honour, and is now probably the foremost scientific authority of the age. My work with Thomson was chiefly experimental, performed in Manchester and the neighbourhood. We pursued the discussion of the thermal effects of fluids in motion until the experiments were interrupted by the action of the owners of the adjacent property, who, on the strength of an obsolete clause in the deeds of conveyance, threatened legal proceedings, the cost of which I did not feel disposed to incur."

Thomson, in fact, though he at first had some difficulty in grasping the significance of the matter, threw himself heart and soul into the new and strange doctrines that heat and work were mutually convertible, and for the next six or eight years, partly in co-operation with Joule, partly independently, he set his unique powers of mind to unravel those mutual relations.

Thomson's mind was essentially metrical. He was never satisfied with any phenomenon until it should have been brought into the stage where numerical accuracy could be determined. He must measure, he must weigh, in order that he might go on to calculate.

"I often say,"* he once remarked, "that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be. . . . The first step toward numerical reckoning of properties of matter, more advanced than the mere reference to a set of numbered standards, as in the mineralogist's scale of hardness, or to an arbitrary trade standard, as in the Birmingham wire-gauge, is the discovery of a continuously varying action of some kind, and the means of observing it definitely, and measuring it in terms of some

* Lecture on "Electrical Units of Measurement," at Institution of Civil Engineers, May 3, 1883. Reprinted in "Popular Lectures and Addresses," vol i., p. 73.

arbitrary unit or scale division. But more is necessary to complete the science of measurement in any department, and that is the fixing on something *absolutely* definite as the unit of reckoning." It was in this spirit that Thomson approached the subject of the transformation of heat. Joule had laid down on certain lines the equivalence of heat and work, and had even measured the numerical value of the equivalent. But before him, in 1824, Carnot, though he proceeded on the fallacious assumption of the material nature of caloric, had in his remarkable book, "Réflexions sur la Puissance Motrice du Feu," discussed the proportion in which heat is convertible into work, and had introduced the very valuable notion of submitting a body to a reversible cycle of operations such that after having experienced a certain number of transformations it is brought back identically to its primitive physical state as to density, temperature, and molecular constitution. He argued, correctly, that on the conclusion of the cycle it must contain the same quantity of heat as that which it initially possessed. But he argued, quite incorrectly, that the total quantity of heat lost by the body during one set of operations must be precisely compensated by its receiving back an equal quantity of heat in the other set of operations. We can see now that this is false; for if it were true none of the heat concerned in the cycle would be transformed into work. Those who were investigating the subject at this time, amongst them Clapeyron, Clausius, and Rankine, perceived this, and noted that since the steam received into the cylinder must be hotter than that expelled from it, the degree to which the transformation is successful must depend on the respective temperatures; a fact moreover recognised by all engineers since the date when Watt discovered the advantage of cooling the exhaust steam by a condenser. Carnot, indeed, proved that the ratio of the work done by a perfect (that is a reversible) engine to the heat received from the source depends on the temperatures of source and condenser only; and when these temperatures are nearly equal the efficiency is expressible by the product of their difference into a certain function of either of them, called "Carnot's function." Rankine went further in pointing out that this function was greater as the temperature in question was lower. But here Thomson's exact mind seized upon the missing essential. Temperatures had hitherto been measured by arbitrary scales based on the expansion of quicksilver, or of air or other gas; and the quicksilver thermometer scale did not agree precisely with that of the air thermometer. He was not satisfied with arbitrary scales. He had this in hand even before his first meeting with Joule, and in June, 1848, communicated to the Cambridge Philosophical Society a paper "On an Absolute Thermometric Scale founded on Carnot's Theory of the Motive Power of Heat, and Calculated from Regnault's Observations." In this paper he set himself to answer the question: Is there any principle on which an absolute thermometric scale can be founded? He arrived at the answer that such a scale is obtained in terms of Carnot's theory, each degree being determined by the performance of

equal quantities of work in letting one unit of heat be transformed in being let down through that difference of temperature. This indicates as the absolute zero of temperature the point which would be marked as −273° on the air-thermometer scale. In 1849 he elaborated this matter in a further paper on "Carnot's Theory," and tabulated the values of "Carnot's function" from 1°C to 231°C. Joule, writing to Thomson in December, 1848, suggested that probably the values of "Carnot's function" would turn out to be the reciprocal of the absolute temperatures as measured on a perfect gas thermometer, a conclusion independently enunciated by Clausius in February, 1850. Independently of Joule, Mayer and Helmholtz had been considering the same problems from a more general standpoint. Helmholtz's famous publication of 1847, "Die Erhaltung der Kraft"—"On the Conservation of Force" (meaning what we now term Energy)—was chiefly concerned with the proposition, based on the denial of the possibility of perpetual motion, that in all the transformations of energy the sum total of the energies in the universe remains constant.

Thomson continued to work at the subject. He experimented on the heat developed by compression of air. He verified the singular prediction of his brother, Professor James Thomson, of the lowering by pressure of the melting-point of ice. He gave a thermodynamic explanation of the non-scalding property of steam issuing from a high-pressure boiler. He formulated, in the years 1851 to 1854, with scientific precision, in a long communication to the Royal Society of Edinburgh, the two great laws of thermodynamics—(1) the law of equivalence discovered by Joule, and (2) the law of transformation, which he generously attributed to Carnot and Clausius. Clausius, indeed, had done little more than put into mathematical language the equation of the Carnot cycle, corrected by the arbitrary substitution of the reciprocal of the absolute temperature; but Thomson never was grudging of the fame of independent discoverers. "Questions of personal priority," he wrote, "however interesting they may be to the persons concerned, sink into insignificance in the prospect of any gain of deeper insight into the secrets of nature."* He gave a demonstration of the second law, founding it upon the axiom that *it is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects.* Further, by a most ingenious use of the integrating factor to solve the differential equation for the quantity of heat needed to alter the volume and temperature of unit mass of the working substance, he gave precise mathematical proof of the theorem that the efficiency of the perfect engine working between given temperatures is inversely proportional to the absolute temperature. In collaboration with Joule, he worked at the "Thermal Effects of Fluids in Motion," the results appearing between the years 1852 and 1862 in a series of four papers in the *Philosophical Transactions*, and four others in the *Proceedings* of the Royal Society. Thus were the foundations of

* Presidential Address, B.A., 1871, and "Popular Lectures," vol. ii., p. 166.

thermodynamics laid. This brilliant development and generalisation of the subject (which had grown with startling rapidity from the moment when Helmholtz denied perpetual motion and Thomson grasped the conception of the absolute zero) did not content Thomson. He must follow its applications to human needs and to the cosmic consequences it involved. And so he not only suggested the process of refrigeration by the sudden expansion of compressed cooled air, but propounded the doctrine of the dissipation of energy. If the availability of the energy in a hot body be proportional to its absolute temperature, it follows that as the earth and the sun—nay, the whole solar system itself—cool down toward one uniform level of temperature, all life must perish and all energy become unavailable. This far-reaching conclusion* once more suggested the question of a beginning, a question which, as already remarked, had arisen in the consideration of the Fourier doctrine of the flow of heat.

In 1852, at the age of twenty-eight, William Thomson married Margaret Crum, and resigned his Cambridge Fellowship. The happiness of his life was, however, shadowed by his wife's precarious health, necessitating residence abroad at various times. In the summer of 1855 they stayed at Kreutznach, from which place Thomson wrote to Helmholtz inviting him to come to England in September to attend the British Association meeting at Glasgow. He assured Helmholtz that his presence would be one of the most interesting events of the gathering, so that he hoped to see him on this ground, but also looked forward with the greatest pleasure to the opportunity of making his acquaintance, as he had desired this ever since the "Conservation of Energy" had come into his hands. Accordingly, on July 29th, Helmholtz left Königsberg for Kreutznach to make the acquaintance of Thomson before his journey to England. On August 6th he wrote to Frau Helmholtz that Thomson had made a deep impression on him.

"I expected to find the man, who is one of the first mathematical physicists of Europe, somewhat older than myself, and was not a little astonished when a very juvenile and exceedingly fair youth, who looked quite girlish, came forward. He had taken a room for me close by, and made me fetch my things from the hotel and put up there. He is at Kreutznach for his wife's health. She appeared for a short time in the evening, and is a charming and intellectual lady, but is in very bad health. He far exceeds all the great men of science with whom I have made personal acquaintance, in intelligence, and lucidity, and mobility of thought, so that I felt quite wooden beside him sometimes." A year later Helmholtz again met the Thomsons at

* "There is at present in the material world a universal tendency to the dissipation of mechanical energy. Within a finite period of time past the earth must have been and within a finite period of time to come the earth must again be unfit for the habitation of man as at present constituted, unless operations have been, or are to be performed, which are impossible under the laws to which the known operations going on at present in the material world are subject."—"Mathematical and Physical Papers," vol. i., p. 514.

Schwalbach. Writing to his father, he described Thomson as "certainly one of the first mathematical physicists of the day, with powers of rapid invention such as I have seen in no other man." In 1860, after the death of Mrs. Helmholtz, the great German philosopher again visited Britain, staying with the Thomsons for some weeks in the island of Arran. In 1863 Helmholtz, who in the meantime had married again, came to England and visited the chief Universities, and in writing to his wife gives an amusing picture of his doings.

"My journey to Glasgow went off very well. The Thomsons have lately moved to live in the University Buildings [the old college]; formerly they spent more time in the country. He takes no holiday at Easter, but his brother James, Professor of Engineering at Belfast, and a nephew who is a student there, were with him. The former is a level-headed fellow, full of good ideas, but cares for nothing except engineering, and talks about it ceaselessly all day and all night, so that nothing else can be got in when he is present. It is really comic to see how the two brothers talk at one another, and neither listens, and each holds forth about quite different matters. But the engineer is the most stubborn, and generally gets through with his subject. In the intervals I have seen a quantity of new and most ingenious apparatus and experiments of W. Thomson, which made the two days very interesting. He thinks so rapidly, however, that one has to get at the necessary information about the make of the instruments, etc., by a long string of questions, which he shies at. How his students understand him, without keeping him as strictly to the subject as I ventured to do, is a puzzle to me; still, there were numbers of students in the laboratory hard at work, and apparently quite understanding what they were about. Thomson's experiments, however, did for my new hat. He had thrown a heavy metal disc into very rapid rotation, and it was revolving on a point. In order to show me how rigid it became on rotation, he hit it with an iron hammer, but the disk resented this, and it flew off in one direction, and the iron foot on which it was revolving in another, carrying my hat away with it and ripping it up."

But we are anticipating. Hitherto Thomson's work had been mainly in pure science; but toward the end of the fifties, while still in the midst of thermodynamic studies, events were progressing which drew him with irresistible force toward the practical applications that made him famous. Indeed, it could hardly be otherwise, seeing that he was master in whatever he touched. Early in 1853 he had communicated to the Glasgow Philosophical Society a paper "On Transient Electric Currents," * in which he investigated mathematically the discharge of a Leyden jar through circuits possessing self-induction as well as resistance. Faraday and Riess had observed that in certain cases the gases produced by the discharge of sparks through

* *Glasgow Philos. Soc. Proc.*, Jan., 1853; *Philos. Magaz.*, June, 1853; and "Mathematical and Physical Papers," vol. i., p. 534.

water consisted of mixed oxygen and hydrogen, and Helmholtz had conjectured that in such cases the spark was oscillatory. Thomson determined to test mathematically what was the motion of electricity at any instant after making contact in a circuit under given conditions. He founded his solution on the equation of energy, ingeniously building up the differential equation and then finding the integral. The result was very remarkable. He discovered that a critical relation occurred if the capacity in the circuit was equal to four times the coefficient of self-induction divided by the square of the resistance. If the capacity was less than this the discharge was oscillatory, passing through a series of alternate maxima and minima before dying out. If the capacity was greater than this the discharge was non-oscillatory, the charge dying out without reversing. This beautiful bit of mathematical analysis, which passed almost unnoticed at the time, laid the foundation of the theory of electric oscillations subsequently studied by Oberbeck, Schiller, Hertz, and Lodge, and forms the basis of wireless telegraphy. Fedderssen in 1859 succeeded in photographing these oscillatory sparks, and sent photographs to Thomson, who with great delight gave an account of them to the Glasgow Philosophical Society.

At the Edinburgh Meeting of the British Association in 1854 Thomson read a paper "On Mechanical Antecedents of Motion, Heat, and Light." Starting with some now familiar, but then novel, generalities about energy, potential and kinetic, and about the idea of *stores of energy*, the author touched on the source of the sun's heat and the energy of the solar system, and then reverted to his favourite argument from Fourier according to which, if traced backwards, there must have been a beginning to which there was no antecedent. This was a non-mathematical exposition of work which, as his note-books show, had been going on from 1850 in a very stiff mathematical form in which Fourier's equations for the flow of heat in solids were applied to a number of outlying problems involving kindred mathematics, including the diffusion of fluids and the diffusion or transmission of electric signals through long cables. The *Proceedings of the Royal Society* for 1854 contain the investigation of cables under the title, "On the Theory of the Electric Telegraph." Faraday had predicted that there would be retardation of signals in cables owing to the coating of gutta-percha acting like the glass of a Leyden jar. Forming the required differential equation, and applying Fourier's integration of it, Thomson drew the conclusion that the time required for the current at the distant end to reach a stated fraction of its steady value would be proportional both to the resistance and to the capacity; and as both of these are proportional to the length of the cable, the retardation would be proportional to the square of the length. This is the famous law of squares about which so much dispute arose. This was followed by a further research, "On Peristaltic Induction of Electric Currents," communicated to the British Association in 1855, and afterward in more complete mathematical form to the Royal Society.

Submarine telegraphy was "in the air." John and Jacob Brett had pioneered the project for a Dover-Calais cable; and in 1851 Crampton successfully united England and France. In 1853 Holyhead and Howth were connected by Mr. (later Sir) Charles Bright. And these were followed by the Dover-Ostend and longer cables. Atlantic telegraphy became the dream of the telegraph engineer. Cyrus W. Field, in 1856, negotiated a cable across the Gulf of St. Laurence, thus connecting Newfoundland to the American continent. The Atlantic Telegraph Company was formed, with capital mostly subscribed in England, to promote the great enterprise to join Ireland to Newfoundland. Field, Brett, Bright, Statham, and Wildman Whitehouse were the chief promoters. Bright was engineer, Whitehouse (a retired medical man) electrician. In a pamphlet issued by the Company, in July, 1857, narrating the preliminary proceedings, the names of John Pender, of Manchester, and Professor Thomson, of "2, The College, Glasgow," are included in the list of the directors; and the statement is made that "the scientific world is particularly indebted to Professor W. Thomson, of Glasgow, for the attention he has given to the theoretical investigation of the conditions under which electrical currents move in long insulated wires, and Mr. Whitehouse has had the advantage of this gentleman's presence at his experiments, and counsel, upon several occasions, as well as the gratification resulting from his countenance and co-operation as one of the directors of the Company." This is one side of the matter. The other side is that Mr. Whitehouse had at the British Association meeting of 1856 read a paper challenging the law of squares, and declaring that if it was true Atlantic telegraphy was hopeless. He professed to refute it by experiments, the true significance of which was disposed of by Thomson in two letters in *The Athenæum*. He pointed out that success lay primarily in adequate section of conductor, and hinted at a remedy (deduced from Fourier's equations) which he later embodied in the curb signal transmitter, namely, that the coefficient of the simple harmonic term in the expression for the electrical potential shall vanish. In December, 1856, he described to the Royal Society his plan for receiving messages, namely, a sort of Helmholtz tangent galvanometer, with copper damper to the suspended needle, the deflexions being observed by watching through a reading telescope the image of a scale reflected from the polished side of the magnet or from a small mirror carried by it. As we all know, he abandoned this subjective method for the objective plan in which a spot of light from a lamp is reflected by the mirror upon a scale. There is a pretty story—which is believed to be true—that the idea of thus using the mirror arose from noticing the reflection of light from the monocle which, being short-sighted, he wore hung round his neck with a ribbon.

The story of the Atlantic cable, of the failure of 1857, of the brief success of 1858, has so often been told that it need not be emphasised here. Thomson, after the failure of the first attempt, was called upon to take a more active part. He had discovered to his surprise that the

conductivity of copper was greatly affected—to an extent of 30 or 40 per cent.—by its purity. So he organised a system of testing conductivity at the factory where the additional lengths were being made, and was put in charge of the test-room on board the *Agamemnon* in 1858. Whitehouse was unable to join the expedition, and Thomson, at the request of the directors, undertook the post of electrician in charge, without any recompense, though the tax on his time and energies was very great. He has recorded (in his Presidential Address of 1889 to this Institution) the following generous note :—

"The first Atlantic cable gave me the happiness and privilege of meeting and working with the late Sir Charles Bright. He was the engineer of this great undertaking, full of vigour, full of enthusiasm. We were shipmates on the *Agamemnon* on the ever-memorable expedition of 1858, during which we were out of sight of land for thirty-three days. To Sir C. Bright's vigour, earnestness, and enthusiasm was due the laying of the cable."

And Bright has given us the following little silhouette of Thomson :—

"As for the Professor . . . he was a thorough good comrade, good all round, and would have taken his 'turn at the wheel' [of the paying-out brake] if others had broken down. He was also a good partner at whist when work wasn't on ; though sometimes, when momentarily immersed in cogibundity of cogitation, by scientific abstraction, he would look up from his cards and ask, 'Wha played what ?'"

After various disheartening mishaps, success crowned their efforts. Throughout the voyage Thomson's mirror galvanometer had been used for the continuity tests and for signalling to shore, with a battery of seventy-five Daniell's cells. The continuity was reported perfect, and the insulation had improved on submersion. On August 5th the cable was handed over to Mr. Whitehouse and reported to be in perfect condition. Whitehouse at once abandoned the Thomson mirror instruments and began working with his own patented apparatus, using heavy relays and a special transmitter with induction coils. He sent in no report to the directors for a week, while he made ineffectual attempts with bigger induction coils to get his apparatus to work. After more than a week the reflecting galvanometer and ordinary Daniell cells were resumed, and then clear messages were interchanged and international congratulations. News of peace with China and of the end of the Indian Mutiny was transmitted ; but the insulation was found to be giving way, and on October 20th, after 732 messages had been conveyed, the cable spoke no more. It had been destroyed by Whitehouse's bungling use of induction coils—some five feet long—working at some 2,000 volts !

Of the part played by Thomson in the next eight years, in preparation for the cables of 1865 and 1866, there is not time to speak. Suffice it to say that throughout the preparations, the preliminary trials, the interrupted voyage of 1865, when 1,000 miles were lost, the

successful voyage of 1866, when the new cable was laid and the lost one recovered from the ocean and completed, Thomson was the ruling spirit whose advice was eagerly sought and followed. On his return he was knighted for the part he had played so well. He had in the meantime made further improvements in conjunction with Cromwell Varley. In 1867 he patented the siphon recorder, and in conjunction with Fleeming Jenkin, the curb-transmitter. He was consulted on practically every submarine cable project from that time forth.

Thomson's activities during the sixties were immense. Beside all this telegraphic work he was incessant in research. He had undertaken serious investigations on the conductivity of copper. He was urging the application of improved systems of electric measurement and the adoption of rational units. When, in 1861, Sir Charles Bright and Mr. Latimer Clark proposed the names of ohm, volt, and farad for the practical units based on the centimetre-gramme-second absolute system, Sir William Thomson gave a cordial support; and on his initiative was formed the famous Committee of Electrical Standards of the British Association, which year by year has done so much to carry to perfection the standards and the methods of electrical measurement. He was largely responsible for the international adoption of the system of units by his advocacy of them at the Paris Congress in 1881, and in subsequent congresses. He was an uncompromising advocate of the metric system, and lost no opportunity of denouncing the "absurd, ridiculous, time-wasting, brain-destroying British system of weights and measures." His lecture in 1883 at the Civil Engineers may be taken as a summary of his views, and it gives one a glimpse of his mental agility. So early as 1851 he had begun to use the absolute system, stimulated thereto by the earlier work of Gauss and Weber. The fact that terrestrial gravity varies at different regions of the earth's surface by as much as half of 1 per cent. compelled the use of absolute methods where any greater accuracy than this is required. "For myself," he said, "what seems the shortest and surest way to reach the philosophy of measurement—an understanding of what we mean by measurement, and which is essential to the intelligent practice of the mere art of measuring—is to cut off all connection with the earth." And so he imagined a traveller with no watch, or tuning fork, or measuring rod, wandering through the universe trying to recover his centimetre of length and his second of time, and reconstructing thereupon his units and standards from the wave-length of the yellow light of sodium, and the value of v the velocity of light from experiments on the oscillations in the discharge of a Leyden jar! Some of us in this very room remember how we listened amazed to this characteristic and bewildering excursus.

Amongst the activities of these fruitful years was a long research on the electrodynamic qualities of metals, thermoelectric, thermoelastic, and thermomagnetic. These formed the subject of his Bakerian lecture

of 1856, which occupies no fewer than 118 pages of the reprinted *Mathematical and Physical Papers*. He worked hard also at the mathematical theory of magnetism. Faraday's work on Diamagnetism had appeared while Thomson was a student at Cambridge. It established the fact that magnetic forces were not mere actions at a distance between supposed poles, but actions dependent on the surrounding medium; and Thomson set himself to investigate the matter mathematically. Faraday and Fourier had been the heroes of Thomson's youthful enthusiasm; and, while the older mathematicians shook their heads at Faraday's heretical notion of curved lines of force, Thomson had, in 1849 and 1850, developed a new theory with all the elegance of a mathematical disciple of Poisson and Laplace, discussing solenoidal and lamellar distributions by aid of the hydrodynamic equation of continuity. To Thomson we owe the terms *permeability* and *susceptibility*, so familiar in the consideration of the magnetic properties of iron and steel. He continued to add to and revise this work through the sixties and seventies.

In 1859–60 Thomson was studying atmospheric electricity, writing on it in Nichol's *Cyclopædia*, and lecturing on it at the Royal Institution. For this study he invented the water-dropping collector, and vastly improved the electrometer, which developed into the elaborate forms of the quadrant instrument and other types described in the B.A. report of 1867. During this work he discovered the fact that the sudden charge or discharge of a condenser is accompanied by a sound. He also measured electrostatically the electromotive force of a Daniell's cell, and investigated the potentials required to give sparks of different lengths in the air.

In the winter of 1860–61 Thomson met with a severe accident. He fell on the ice when engaged at Largs in the pastime of curling, and broke the neck of his thigh. For several months he had to lie on his back; and it was at this time that he adopted the famous green notebooks, which ever afterwards were the companions of his days. The accident left him with a slight limp for the rest of his life.

An admirable picture of Lord Kelvin as he was in the sixties, moving among his students and incessant in his researches, has been given in *The Times* of January 8, 1908, by Professor Ayrton, who was then working at Glasgow. In these years Thomson was also writing on the secular cooling of the earth, and investigating the changes of form during rotation of elastic spherical shells. And, as if this were not enough to have in hand, he embarked with his friend Professor Tait on the preparation of a text-book of Natural Philosophy. There was at that date no satisfactory work to put into the hands of students, and he must supply the need. At first a short pamphlet of propositions on statics and dynamics, culled by Professor John Ferguson from mere lecture notes, was printed for the use of students. Thomson had told Helmholtz of his purpose, and in 1862 Helmholtz wrote him: "Your undertaking to write a text-book of Natural Philosophy is very praiseworthy, but will be exceedingly tedious. At the same time I hope it will

suggest ideas to you for much valuable work. It is in writing a book like that that one best appreciates the gaps still left in science." The first volume of Thomson and Tait's "Treatise on Natural Philosophy" was published in 1867, the second only in 1874; when it appeared that Helmholtz's hopes were just. For in approaching the subject of elasticity the gaps still left were found to be such that whole new mathematical researches were necessary before Volume II. could be finished. Thomson's contributions to the theory of elasticity are no less important than those he made to other branches of physics. In 1867 he communicated to the Royal Society of Edinburgh his famous paper "On Vortex Atoms." Helmholtz had published a mathematical paper on the hydrodynamic equations of vortex motion, proving that closed vortices could not be produced in a liquid perfectly devoid of internal friction. Thomson seized on this idea. If no such vortex could be artificially produced, then if such existed it could not be destroyed. But being in motion and having the inertia of rotation, it would have elastic and other properties. He showed that vortex-rings (like smoke-rings in air) in a perfect medium are stable, and that in many respects they possess the qualities essential to the properties of material atoms —permanence, elasticity, and power to act on one another through the medium at a distance. The different kinds of atoms known to the chemist as elements were to be regarded as vortices of different degrees of complexity. Though he seemed at the end of his life to doubt whether the vortex-atom hypothesis was adequate to explain all the properties of matter, the conception remains to all time a witness to his extraordinary powers of mind.

In 1870 Lady Thomson, whose health had been failing for several years, died. In the same year the University of Glasgow was removed from the site it had occupied for over four centuries to the new and splendid buildings on Gilmore Hill, overlooking the Kelvin River. Sir William Thomson had a house here in the terrace assigned for the residences of the professors, adjoining his laboratory and lecture-room. From his youth he had been fond of the sea, and had early owned boats of his own on the Clyde. For many years his sailing yacht, the *Lalla Rookh*, was conspicuous, and he was an accomplished navigator. His experiences in cable-laying had taught him much, and in return he was now to teach science in navigation. First he reformed the mariners' compass, lightening the moving parts to avoid protracted oscillations, and to facilitate the correction of the quadrantal and other errors arising from the magnetism of the ship's hull. At first the Admiralty would have none of it. Even the Astronomer Royal condemned it. "So much for the Astronomer Royal's opinion," he ejaculated. But the compass is now all but universally adopted both in the Navy and in the Mercantile Marine.

Dissatisfied with the clumsy appliances used in sounding, when the ship had to be stopped before the sounding line could be let down, he devised the now well-known apparatus for taking flying soundings

by using a line of steel piano wire. He had great faith in navigating by use of sounding line, and once told me—*àpropos* of a recent wreck near the Lizard, which he declared would have been impossible had soundings been regularly taken—how, in a time of continuous fog, he brought his yacht all the way across the Bay of Biscay into the Solent trusting to soundings only. He also published a set of tables for facilitating the use of Sumner's method at sea. He was vastly interested in the question of the tides, not merely as a sailor, but because of the interest attending their mathematical treatment in connection with the problems of the rotation of spheroids, the harmonic analysis of their complicated periods by Fourier's methods, and their relation to hydrodynamic problems generally. He invented a tide-predicting machine, which will predict for any given port the rise and fall of the tides, which it gives in the form of a continuous curve recorded on paper; the entire curves for a whole year being inscribed by the machine automatically in about four hours. Further than this, adopting a beautiful mechanical integrator, the device of his ingenious brother, Professor James Thomson, he invented a harmonic analyser—the first of its kind—capable not only of solving differential equations of any order, but of analysing any given periodic curve and exhibiting the values of the coefficients of the various terms of the Fourier series. Wave problems always had a fascination for him, and the work of the mathematicians Poisson and Cauchy on the propagation of wave-motion were familiar studies. In his lectures he used to say, "The great struggle of 1815"—and then paused, while his students, thinking of Waterloo, began to applaud—"was not that fought out on the plains of Belgium, but—who was to rule the waves, Cauchy or Poisson?" In 1871 Helmholtz went with Sir William Thomson on the yacht *Lalla Rookh* to the races at Inverary, and on some longer excursions to the Hebrides. Together they studied the theory of waves, "which he loved," says Helmholtz, "to treat as a race between us." Returning they visited many friends. "It was all very friendly," wrote Helmholtz, "and unconstrained. Thomson presumed so much on his intimacy with them that he always carried his mathematical note-book about with him, and would begin to calculate in the midst of the company if anything occurred to him, which was treated with a certain awe by the party." He possessed indeed the faculty of detachment, and would settle quietly down with his green book almost unconscious of things going on around him. On calm days he and Helmholtz experimented on the rate at which the smallest ripples on the surface of the water were propagated. Almost the last publications of Lord Kelvin were a series of papers on "Deep Sea Ship Waves," communicated between 1904 and 1907 to the Royal Society of Edinburgh.

In 1874, on June 17th, Sir William Thomson married Miss Frances Anne Blandy, of Madeira, whom he had met on cable-laying expeditions. Lady Kelvin, who survives him, became the centre of his home in Glasgow and the inseparable companion of all his later travels. He built at Netherhall, near Largs, a beautiful mansion in the Scottish

baronial style; and though he latterly had a London house in Eaton Place, Netherhall was the home to which he retired when he withdrew from active work in the University of Glasgow.

Throughout the seventies and eighties Sir William Thomson's scientific activities were continued with untiring zeal. In 1874 he was elected President of the Society of Telegraph Engineers, of which, in 1871, he had been a foundation member and Vice-President. In 1876 he visited America, bringing back with him a pair of Graham Bell's earliest experimental telephones. He was President of the Mathematical and Physical Section of the British Association of that year at Glasgow.

Amongst the matters that cannot be omitted in any notice of his life was Lord Kelvin's controversy with the geologists. He had from three independent lines of argument inferred that the age of the earth could not be infinite, and that the time demanded by the geologists and biologists for the development of life must be finite. He himself estimated it at about a hundred million of years at the most. In vain did the naturalists, headed by Huxley, protest. He stuck to his propositions with unrelaxing tenacity but unwavering courtesy. "Gentler knight never broke lance," was Huxley's dictum of his opponent. His position was never really shaken, though the later researches of Perry, and the discovery by Strutt of the degree to which the constituent rocks of the earth contain radioactive matter, the disgregation of which generates internal heat, may so far modify the estimate as to increase somewhat the figure which he assigned.

The completion of the second volume of the Thomson and Tait "Treatise"—no more was ever published—and the collection of his own scattered researches, was a work extending over some years. In addition he wrote for the *Encyclopædia Britannica*, of 1879, the long and important articles on "Elasticity" and on "Heat."

In 1871 he was President of the British Association at its meeting in Edinburgh. In his Presidential Address, which ranged luminously over the many branches of science within the scope of the Association, he propounded the suggestion that the germs of life might have been brought to the earth by some meteorite.

With the advent of electric lighting at the end of the seventies Thomson's attention was naturally attracted to this branch of the practical applications of science. He never had any prejudice against the utilisation of science for practical ends.

"There cannot," he wrote, "be a greater mistake than that of looking superciliously upon practical applications of science. The life and soul of science is its practical application; and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science, so in physical science many of the greatest advances that have been made from the beginning of the world to the present time have been made in the earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind."

And so he scorned not to devise instruments and appliances for commercial use. His electrometers, his galvanometers, his siphon-recorders, and his compasses had been made by James White, optician, of Glasgow. In this firm he became a partner, taking the keenest commercial interest in its operations, and frequenting the factory to superintend the construction of apparatus. New measuring instruments were required. He set himself to devise them, designing potential galvanometers, ampere gauges, and a whole series of standard electric balances for electrical engineers.

Lord Kelvin's patented inventions were very numerous. Without counting in those since 1900, taken mostly in the name of Kelvin and James White, they number 56. Of these 11 relate to telegraphy, 11 relate to compasses and navigation apparatus, 6 relate to dynamo machines or electric lamps, 25 to electric measuring instruments, 1 to the electrolytic production of alkali, and 2 to valves for fluids. He was an independent inventor of the zigzag method of winding alternators, which the public knew under the name of Ferranti's machine, which was manufactured under royalties payable to him. He was interested even in devising such details as fuses and the suspension pulleys with differential gearing by which incandescent lamps can be raised or lowered.

He gave evidence before a Parliamentary Committee on Electric Lighting, and discussed the theory of the electric transmission of power, pointing out the advantage of high voltages. The introduction into England in 1881 of the Faure accumulator excited him greatly. In his Presidential Address to the Mathematical and Physical Section of the British Association at York that year he spoke of this and of the possibility of utilising the powers of Niagara. He also read two papers, in one of which he showed mathematically that in a shunt dynamo best economy of working was attained when the resistance of the outer circuit was a geometric mean between the resistances of the armature and of the shunt. In the other he laid down the famous law of the economy of copper lines for the transmission of power.

Helmholtz, visiting him again in 1884, found him absorbed in regulators and measuring apparatus for electric lighting and electric railways. "On the whole," Helmholtz wrote, "I have an impression that Sir William might do better than apply his eminent sagacity to industrial undertakings; his instruments appear to me too subtle to be put into the hands of uninstructed workmen and officials. . . . He is simultaneously revolving deep theoretical projects in his mind, but has no leisure to work them out quietly; as far as that goes, I am not much better off!" But he shortly added, "I did Thomson an injustice in supposing him to be wholly immersed in technical work; he was full of speculations as to the original properties of bodies, some of which were very difficult to follow; and, as you know, he will not stop for meals or any other consideration." And indeed Thomson had weighty things in his mind. He was revolving over the speculations which later in the same year he was to pour out in such marvellous

abundance in his famous twenty lectures in Baltimore, "On Molecular Dynamics and the Wave Theory of Light." These lectures, delivered to twenty-six hearers, mostly accomplished teachers and professors, were reported verbatim at the time, and reprinted by him with many revisions and additions in 1904. Of this extraordinary work, done at the age of sixty, it is difficult to speak. Day after day he led the twenty-six "coefficients" who sat at his feet, through the mazes of the solid-elastic theory and the spring-shell molecule, newly invented in order to give a conception how the molecules of matter are related to the ether through which light-waves are propagated. All his life he had been endeavouring to discover a rational mechanical explanation for the most recondite phenomena—the mysteries of magnetism, the marvels of electricity, the difficulties of crystallography, the contradictory properties of ether, the anomalies of optics. While Thomson had been seeking to explain electricity and magnetism and light dynamically, or as mechanical properties, if not of matter, at least of ether, Maxwell (the most eminent of his many disciples) had boldly propounded the electromagnetic theory of light, and had drawn all the younger men after him in acceptance of the generalisation that the waves of light were essentially electromagnetic displacements in the ether. Thomson had never accepted Maxwell's theory. It is true that in 1888 he gave a nominal adhesion, and in the preface which, in 1893, he wrote to Hertz's "Electric Waves," he himself uses the phrase "the electromagnetic theory of light, or the undulatory theory of magnetic disturbance." But later he withdrew his adhesion, preferring to think of things in his own way. Thomson's Baltimore lectures, abounding as they do in brilliant and ingenious points, and ranging from the most recondite problems of optics to speculations on crystal rigidity, the tactics of molecules and the size of atoms, leave one with the sense of being a sort of protest of a man persuaded against his own instincts, and struggling to find new expression of his thoughts so as to retain his old ways of regarding the ultimate dynamics of physical nature.

One characteristic of all Lord Kelvin's teaching was his peculiar fondness for illustrating recondite notions by models. Possibly he derived this habit from Faraday; but he pushed its use far beyond anything prior. He built up chains of spinning gyrostats to show how the rigidity derived from the inertia of rotation might illustrate the property of elasticity. The vortex-atom presented a dynamical picture of an ideal material system. He strung together little balls and beads with sticks and elastic bands to demonstrate crystalline dynamics. On the use of the model to illustrate physical principles he spoke as follows at Baltimore:—

"My object is to show how to make a mechanical model which shall fulfil the conditions required in the physical phenomena that we are considering, whatever they may be. At the time when we are considering the phenomena of elasticity in solids I shall want a model of that. At another time, when we have vibrations of light to consider,

I shall want to show a model of the action exhibited in that phenomenon. We want to understand the whole about it; we only understand a part. It seems to me that the test of 'Do we or do we not understand a particular subject in physics?' is: 'Can we make a mechanical model of it?' I have an immense admiration for Maxwell's mechanical model of electromagnetic induction." And again, Lord Kelvin says: "I never satisfy myself until I can make a mechanical model of a thing. If I can make a mechanical model, I can understand it. As long as I cannot make a mechanical model all the way through I cannot understand it."

This use of models is indeed to be found in the work of every follower of Faraday. Maxwell designed physical models as we have seen. FitzGerald conceived a remarkable model of the æther. Andrew Gray has liberally employed them. The work of Sir Oliver Lodge teems with models of all sorts. It has become characteristic of the tone and temper of British physicists, of none more than of Lord Kelvin. Where Poisson or Laplace saw a mathematical formula, Kelvin with true physical imagination discerned a reality which could be roughly simulated in the concrete. And throughout all his mathematics his grip of the physical reality never left him. According to the standard that Kelvin set before him, it is not sufficient to apply pure analysis to obtain a solution that can be computed. Every equation, "every line of the mathematical process must have a physical meaning, every step in the process must be associated with some intuition, the whole argument must be capable of being conducted in concrete physical terms." * In other words, Lord Kelvin, being a highly accomplished mathematician, used his mathematical equipment with supreme ability as a tool: he remained its master and did not become its slave.

Once Lord Kelvin astonished the audience at the Royal Institution by a discourse on "Isoperimetrical Problems," endeavouring to give a popular account of the mathematical process of determining a maximum or minimum, which he illustrated by Dido's task of cutting an ox-hide into strips so as to enclose the largest piece of ground; by Horatius Cocles's prize of the largest plot that a team of oxen could plough in a day; and by the problem of running the shortest railway line between two given points over uneven country. On another occasion he entertained the Royal Society with a discourse on the "Homogeneous Partitioning of Space," in which the fundamental packing of atoms was geometrically treated, affording incidentally the theory of the designing of wall-paper patterns.

To the last Lord Kelvin took an intense interest in the most recent discoveries. Electrons—or "electrions," as he called them—were continually under discussion. He prided himself that he had read Rutherford's book on "Radioactivity" again and again. He objected, however, *in toto* to the notion that the atom was capable of division or disintegration. In 1903, in a paper called "Æpinus Atomized," he reconsidered the views of Æpinus and Father Boscovitch from

* Professor A. E. H. Love.

the newest standpoint, modifying Æpinus's theory to suit the notion of electrions.

After taking part in the British Association meeting of 1907 at Leicester, where he entered with surprising activity into the discussions of radioactivity and kindred questions, he went to Aix-les-Bains for change. He had barely reached home at Largs in September when Lady Kelvin was struck down with a paralytic seizure. Lord Kelvin's misery at her helpless condition was intense. He had himself suffered for fifteen years from recurrent attacks of facial neuralgia, and in 1906 underwent a severe operation. Under these afflictions he had visibly aged, and the illness of Lady Kelvin found him little able physically to sustain the anguish of the stroke. He wandered distractedly about the corridors of his house unable at last to concentrate his mind on work in hand. A chill seized him, and after about a fortnight of prostration he sank slowly and quietly away.

He was buried in Westminster Abbey, with national honours, on December 23, 1907.

The sympathies of all of us go out to the gracious lady who survives him, and who with such assiduous devotion tended him in his declining years.

Honours fell thickly on Lord Kelvin in his later life. He was President of the Royal Society from 1890 to 1894. He had been made a Fellow of the Royal Society in 1851, and in 1883 had been awarded the Copley medal. He was raised to the peerage in 1892. He was one of the original members of the Order of Merit founded in 1902, was a Grand Officer of the Legion of Honour, and held the Prussian Order *Pour le Mérite*. In 1902 he was named a Privy Councillor. In 1904 he was elected Chancellor of the University, in which he had filled the Chair of Natural Philosophy for fifty-three years. He had celebrated his jubilee with unusual marks of world-wide esteem, in 1896; and finally retired in 1899. He was a member of every foreign Academy, and held honorary degrees from almost every University. In 1899 we elected him an Honorary Member of our Institution.

In politics he was, up to 1885, a broad Liberal; but, as was natural in an Ulsterman, became an ardent Unionist on the introduction of the Home Rule Bill. He once told me that he preferred Chamberlain's plan of Home Rule with four Irish Parliaments—one in each province.

In religion Lord Kelvin was an Anglican—at least from his Cambridge days—but when at Largs attended the Presbyterian Free Church. His simple, unobtrusive, but essential piety of soul was unclouded. He had a deep detestation of ritualism and sacerdotalism, which he hated heart and soul in all its forms; and he denounced spiritualism as a loathsome and vile superstition. His profound studies had led him again and again to contemplate a beginning to the order of things, and he more than once publicly professed a profound and entirely unaffected belief in Creative Design.

Kindly-hearted, lovable, modest to a degree almost unbelievable, he

carried through life the most intense love of truth and an insatiable desire for the advancement of natural knowledge. Accurate and minute measurement was for him as honourable a mode of advancing knowledge as the most brilliant or recondite speculation. At both ends of the scale his pre-eminence in the quest for truth was unchallenged. If he could himself at the end of his long career describe his own efforts as "failure," it was because of the immensely high ideal* which he set before him. "I know," he said on the day of his jubilee, "no more of electric and magnetic force, or of the relation between ether, electricity, and ponderable matter, or of chemical affinity, than I knew and tried to teach to my students in my first session." Yet which of us has not learned much of these things because of his work? We of this Institution may well be proud of him—proud that he was one of our first members, that he was thrice our President, and that as our President he died. We shall not look upon his like again.

Sir William Preece.

Sir WILLIAM PREECE, K.C.B., F.R.S. (Past President): Professor Silvanus Thompson,—I know that I voice the feelings of every one present to-night when I say that we have enjoyed a delightful hour and a half in listening to the reading of one of the best digested memorials I have ever listened to, couched in the simplest and most beautiful English language, of which you are a master, touched up with brilliant flashes of scientific truths, and giving us in the simplest possible way an idea of the work of that great man whose loss we so deeply deplore. You have made it agreeable to us, because you have given delightful little touches of humour which have withdrawn from it any conception of its being a doleful memorial service. It will leave upon us the impression of being a witty, learned, sensible condensation of the work of the great life which has gone. I stand here, as one who for over half a century claimed an intimate acquaintance with our great chief, to propose that a vote of thanks be given to you for the graceful tribute you have given us to-night. I will not take advantage of this fact to say a word of my own feelings in the matter; I will simply say that, as a man, while he lived I loved him, and now that he is dead I revere him. During the short remainder of my very long experience as an electrical engineer I will take every chance and opportunity of glorifying, if I can, the work that Professor Thompson has expounded to-night. Gentlemen, it is my duty to propose that a vote of thanks be accorded to Professor Silvanus Thompson for the address we have listened to, and to ask his permission for the lecture to be printed in the Journal of our Proceedings.

Professor Carey Foster.

Professor CAREY FOSTER, F.R.S. (Past President): I feel it a very great honour to be allowed to second the vote of thanks which Sir William Preece has so well proposed. We are greatly indebted to

* He conceived the possibility of formulating a comprehensive molecular theory, definite and complete, "in which all physical science will be represented with every property of matter shown in dynamical relation to the whole."—"Presidential Address to the British Association," 1871, reprinted in "Popular Lectures and Addresses," vol. ii, p. 163.

Professor Foster.

Professor Thompson for the address which he has given us. To speak on such a subject at all adequately in the short time allowed for one of our addresses is not an easy thing to do, but I think we must all recognise that Professor Silvanus Thompson has most worthily fulfilled a noble task. I cannot quite equal Sir William Preece in claiming half a century's friendship with Lord Kelvin, but I can go pretty near it. I first had the honour of making his acquaintance in, I think, 1862, and I shall never forget the kindness and generosity which he showed to me as a young man, or his more than generous appreciation of any work which he considered was genuine and true of its kind. The work Lord Kelvin did would have broken down any other man; but he never seemed weary, and he was never too full of his own business to be able to give attention to any claim upon him from others. Professor Thompson has touched upon almost every point of his immense output of scientific work, and in doing so he has given us, not a mere catalogue, but an intelligible and discriminating account of his essential results. My own thoughts go back to Lord Kelvin, perhaps, even more as a man than as an illustrious leader of science, but in both aspects his is a memory that not only we, but the nation, may be proud of. We have to thank Professor Thompson for a most excellent account of this great man, whose loss we all so keenly deplore.

The resolution of thanks was then put to the meeting and carried by acclamation.

ELECTROLYTIC CORROSION.

By Professor W. W. HALDANE GEE, Associate Member.

(*Paper received from the* MANCHESTER LOCAL SECTION, *March* 4, *and read at Manchester on March* 31, 1908.)

I.—CLASSIFICATION.

From time to time serious cases of metallic corrosion having been brought under my notice, it was decided to collect evidence relating to its cause and to make experiments on the subject.

In this task it was soon found that a convenient hypothesis is that all corrosion is essentially electrolytic. Adopting this view a wide field is open to study, and the subject may be conveniently divided as follows:—

1. Corrosion produced by an external E.M.F. or ordinary electrolysis.
2. Corrosion resulting from the contact of different metals.
3. Ordinary or self-corrosion.
4. Corrosion produced by alternating currents.
5. Corrosion produced by the combinations of the above cases.

II.—THE E.M.F. EXTERNAL ANODE PHENOMENA.

When an electric current is passed through an electrolyte, such as a solution of sodium chloride, with an anode like copper, the electrochemical effect of the negative ions will be to dissolve a mass of the anode, whose theoretical amount may be calculated by the law of Faraday. In practice this value may be exceeded or the efficiency of the process may be very small.

The subject of anodic corrosion until comparatively recently has not received much attention. An important modern contribution to our knowledge is due to Wohlwill,* who has shown that in the case of copper the anode may lose 23 per cent. by mechanical disintegration alone.

A high anode efficiency is important in the electrolytic refining and the electroplating industries. Each case will vary according to the nature of the anodes (as to constitution and kind of surface), the electrolyte used and its temperature, and especially depends on the current density employed. Thus nickel with a current density of 0·05 ampere per square decimetre may dissolve quantitatively in sulphuric acid or become passive in sodium nitrate and remain unattacked.†

* "Das Zerfallen der Anode," *Zeitschrift für Elektrochemie*, vol. 9, p. 311, 1903.

† M. G. Levi, *Gazzeta Chimica Italiana*, vol. 35, part 1, p. 391, 1905.

Again it has been shown that electrolytic nickel anodes may only give an anode efficiency of 12·7 per cent., whilst cast nickel anodes roughened with acids may have an anode efficiency as high as 91·3 per cent.* Nickel anodes are peculiar in becoming pitted at a number of points, holes being soon formed in places, but in other parts the original thickness of the plates remains intact.†

III.—Experiments on Anodic Corrosion.

The following experiments have been made either by directly weighing the dried electrodes or by using the method of balanced electrodes as described by me.‡ The anode is weighed from time to time in the electrolyte and the real loss calculated from the density of the metal and that of the electrolyte.

In the tests with copper a solution containing 32 oz. of copper sulphate crystals and 12·6 oz. of sulphuric acid to the gallon of water was used. The anode was of good sheet copper of 10 sq. in. total surface. After corrosion the anode was gently cleaned. At the higher current densities a strongly adherent film of a black colour was formed, and the results were very irregular.

When pure electrolytic copper was substituted the values obtained were :—

Current Density. Amperes per Square Inch.	Anode Efficiency. Per Cent.
0·010	103·6
0·050	110·5
0·100	108·6

These limits of current density thus all give greater corrosion than the theoretical amount, copper being assumed to be a diad.

IV.—Passivity of Metals.

Under certain conditions a corrodible metal behaves, when it is made the anode, as if it were a noble metal. For this passive condition the most obvious explanation is that a film of insoluble oxide is formed, which prevents further attack, and no doubt that in some cases this is the fact. Many researches have been made on the subject, and quite an extensive literature of the rival theories might be quoted. Practically the effect is of great importance in the prevention of metals from corrosion by stray currents, as will be shown later in this paper.

Experiments on Passivity.

The iron used in all the experiments was transformer iron.

1. *Sodium carbonate,* half normal. Electrodes 110 sq. cms., 5 cms. apart. A very clean electrolysis, no sign of passivity until a current density of 3·14 amperes per square centimetre.

2. *Sodium bicarbonate,* half normal. Plates as before. Traces of

* O. W. Brown, *Transactions of the American Electrochemical Society*, vol. 4, p. 81, 1905.

† A. Brochet, *Comptes Rendus*, vol. 145, p. 627, 1907.

‡ *Transactions of the Faraday Society*, vol. 1, p. 237, 1905.

passivity at 0·00213, 0·00674, and 0·0254 current densities. At 0·339 a more marked passivity.

3. *Sodium nitrate*, half normal. Plates as before. The iron easily dissolves until a current density of 3·5 is reached, when a strong film formed at the anode.

4. The effect of limiting the space about one of the electrodes was tried. One electrode was placed within a small porous pot. The other electrode was placed in a large outside vessel.

Potassium carbonate (10 per cent.), with limited anode space. Indications of passivity at 0·00054, 0·00215, and 0·00645, which were more marked at 0·060 and 0·086. At a much higher current density of 2·24 the following observations were recorded:—

TABLE I.

Current, Amperes.	Volts.	Temperature, °C.	Remarks.
14·0	40–90	38·4	Strong passivity volts vary from 40–90.
14·0	30–110	41	Intermittent film on anode, becoming finally steady.
14·0	70	—	Fairly constant.
11·5	160	46	Fairly constant.
2·0	220	48	Good film for 5 min., and then the cathode burnt up with a bright light.

5. *Sodium nitrate* (10 per cent.), with limited *cathode* space. The volts were gradually increased from 0·013 to 0·73, when a passive stage was reached, which was fairly constant with a current density of 0·0045 and 16° C. On continuing to raise the voltage gradually the current fluctuations were very marked. Just before each current rush a cloud of gas appeared at the anode. The film then cleared off, but was re-formed at a higher voltage. These effects were often repeated up to a current density of 0·0134, the voltage being 18·2 and the temperature 23° C. At this point the anode was quite bright and clean.

6. *Sodium nitrate* (10 per cent.), with limited *anode* space. In the previous experiment, the anode being surrounded by a large quantity of electrolyte, there was opportunity for the products of the anodic reaction to dissolve off or diffuse from the anode, but in the experiment now to be described much more regular action may be expected. This was found to be the case. The volts were gradually increased from 0·025 with a corresponding increase of the current until 0·40 was reached. A variable stage was then reached when a strong passive stage was produced with a current density of 0·003 at 17° C.

7. In later observations the potential of each electrode has been measured. Experiments have also been made with sand, etc., moistened with electrolytes.

V.—Applications of Anodic Corrosion.

Anodic corrosion furnishes convenient methods for the preparation of plating solutions and insoluble oxides and compounds. The anodic stripping of tinned iron is now an established industry.* Electrolysis may be employed for the drilling of holes in hard steel plates.† Efforts are being made for the application of anodic etching in the printing, photographic processes. ‡

In this last direction a number of experiments have been made with the view of replacing the acid etching of zinc plates by electrolysis. When the depth of etching that is required is small the process is successful, but on the other hand, when the time (for press purposes) must be limited many difficulties are encountered. To etch a depth of $\frac{1}{10}$th of an inch in 25 minutes requires a high current density, and means must be taken to remove the bubbles of gas from the surface; then, again, the temperature must not be allowed to rise sufficiently high to injure the ink employed in making the drawing. It will be an advantage to the workman to replace the nitric acid at present used for a neutral salt, such as zinc sulphate.

VI.—Applications of the Cathode Effects.

When solutions of alkalies and their salts are used as electrolytes with iron cathodes, the effect of the liberated hydrogen will be to reduce any oxide films and leave the surface clean; beyond this there will be no further attack, for the alkaline solutions have no power of rusting iron. These facts may be utilised for the cleaning of iron and steel articles and for the prevention of corrosion.

Electrolytic Cleaning.—This method is coming into favour and is now often used instead of acid pickles.§

We have found that the following process gives very successful results: A 10 per cent. solution of caustic soda is placed in a large iron vessel, and a sheet of good soft iron is bent in a circular shape so as to fit closely to the sides of the vessel. This is used as the anode. The solution is heated to boiling, and the iron to be cleaned is attached to the negative pole and immersed in the solution. Thus in one test a sheet of iron of 40 sq. in. total surface (that was covered with rust and grease) was used and a current of 2 amperes was passed for 5 minutes. On removing the plate it was found that most of the rust could be

* See H. Mennicke, *Zeitschrift für Electrochemie*, vol. 8, p. 315, 1902; Kershaw, *Electrician*, vol. 58, p. 638, 1907.

† Cowper-Coles, *Electrical Review*, vol. 47, p. 131, 1900.

‡ *Elektrotechnische Rundschau*, vol. 17, p. 139, 1900; German Patents 815,675, 21,322, 1904; 28,319, 1906. J. Rieder, *Zeitschrift für Elektrochemie*, vol. 9, p. 911, 1903.

§ See C. F. Burgess, *Electrical World*, vol. 32, p. 445, 1898; H. S. Coleman, *Transactions of the Faraday Society*, vol. 2, p. 53, 1906.

removed by simple washing, and the application of a brush brought the surface at once bright.

Cathodic Protection of Metals.—This is the method most frequently recommended to protect underground ironwork against stray currents. It may be also used in chemical works and in manufacturing processes where metal is brought in contact with corrosive liquids.

H. S. Anderson and J. W. Bennie protect the metallic screens used in mining plant against the action of acids and salts by making them cathodes against a carbon or other suitable anode. They are then able to use steel wire or punched steel screens, which are much less expensive than those made of brass or copper.* To prevent the surface condenser tubes from corrosion at the Long Island power station of the Pennsylvania Railroad Company a small booster is used, the negative pole of which is connected to seven points in each condenser.† J. H. Schoenberger and G. W. Frazier have designed a method for protecting the metal sheathing of ships by making it a cathode.‡

VII.—Simple Galvanic Couples.

When two metals are in contact and are completely immersed in an electrolyte the arrangement constitutes a short-circuited primary cell, which is ideal in simplicity from a constructional point of view, but electrically it is of great complexity. Thus, to take an example, suppose that we place two equal cylinders of lead and zinc in a solution of sulphuric acid without any connection between them, and find the potential difference to be 0·77 volt. If we then connect them by an external wire and measure the acting voltage, it will now be much lower than the open circuit value, for hydrogen on the lead will produce a back-voltage of, say, 0·64, and will give a working value of about 0·13. Let next the two cylinders be placed with their curved surfaces in contact and their axes parallel. Let them be placed upright in the centre of a large cylindrical vessel containing dilute sulphuric acid. The zinc will begin to dissolve and the corrosion will be particularly rapid along the boundaries between the two metals.

Let E be the effective voltage and R the resistance between the cylinders measured between the curved surfaces and the electrolyte. The value of R will depend on the conductivity k of the electrolyte and the arrangement of the stream lines. Denoting a quantity, depending on the size of the cylinders and on that of the containing vessel, the *conductance capacity* or K, we have for the current C flowing—

$$C = k K E.$$

But by Faraday's law—

$$M = C t z$$

* U.S. Patents 796,172 and 706,390, 1905.
† *Electrician*, vol. 57, p. 172, 1906.
‡ U.S. Patent 13,074, 1907.

where M = grammes of zinc are dissolved in time t, and z = the electrochemical equivalent of the zinc.

Hence the velocity U of the solution of the zinc will be—

$$U = M/t = C z = k K z E.$$

This formula, then, enables the reaction velocity to be determined, for k and z are physical constants, E can be obtained experimentally, and the value of K can be calculated. The task of finding K has been kindly undertaken by Mr. S. Butterworth. His results are given in Appendix A.

To take the example of the case of the two cylinders described above. Let the whole of the two cylinders be insulated from the electrolyte, excepting the two outer hemi-cylindrical surfaces. Then using the symbols as in the case of Fig. 22 (Appendix A)—

$$K = \frac{a\,b}{a+b}\left(\frac{c_1+c_2}{c_1\,c_2} - \frac{d_1+d_2}{d_1\,d_2}\right).$$

But since $a = b$, $a = c_1 = c_2$, and $d = d_1 = d_2$, then—

$$K = a\,(1/a - 1/d) \text{ per unit length.}$$

If the cylinders be of diameters = 1·15 cms., and of lengths (l) = 3·3 cms., and are placed in a large cylindrical vessel of 23·5 cms. diameter, then—

$$a = 0{\cdot}575 \text{ cms.}, \quad \text{and} \quad d = 5{\cdot}88 \text{ cms.}$$

Hence—

$$K = l\,a\,(1/a - 1/d) = 2{\cdot}98.$$

If the electrolyte be 5 per cent. sulphuric acid, then $k = 0{\cdot}209$ at 18° C., and z for zinc = 0·00034, hence—

$$U = 0{\cdot}209 \times 2{\cdot}98 \times 0{\cdot}00034 \times E = 0{\cdot}000212\,E \text{ grammes per second.}$$

VIII.—The Effective Voltage.

This will depend on the nature of the metals, the concentration and the nature of the electrolyte and its temperature, and on the action of the hydrogen at the cathode. This last effect has been studied by Caspari, Tafel, Law and Chapman, and Nutton and Law.* The potential of the hydrogen at the cathode surface is known as the *Ueberspannung, over-voltage,* and *super-tension.* It depends, among other circumstances, on the nature of the metal and the physical state of its surface. Over-voltage plays an important *rôle* in the solution of metals. Thus the reason that amalgamated zinc does not dissolve easily in acid is because the over-voltage of the mercury renders the effective voltage practically zero. For metals which occlude hydrogen the over-voltage is small, hence platinum is a very effective member of a galvanic couple.

* Caspari, *Zeitschrift für Physik. Chemie,* vol. 30, p. 89, 1899. Caspari, *Zeitschrift für Electrochemie,* vol. 6, p. 37, 1899. Tafel, *Zeitschrift für Physik. Chemie,* vol. 50, p. 712, 1905. Chapman and Law, *Analyst,* vol. 31, p. 5, 1906. Law, *Transactions of the Faraday Society,* vol. 2, p. 72, 1906; vol. 3, p. 50, 1907.

Measurements of the over-voltage that have hitherto been made do not apply to the conditions of galvanic couples. The anode and cathode compartments have been, as a rule, kept separate, and so important secondary reactions have been avoided. A separate investigation becomes therefore necessary.

To get some idea of the value of the working pressure the following experiment has been made :—

A plate of iron 2 in. × 6 in. was fixed at a distance of about ¼ in. from a plate of zinc of the same size so as to constitute a voltaic cell in a normal solution of sodium chloride. The poles were connected with various resistances and the P.D. was observed from time to time

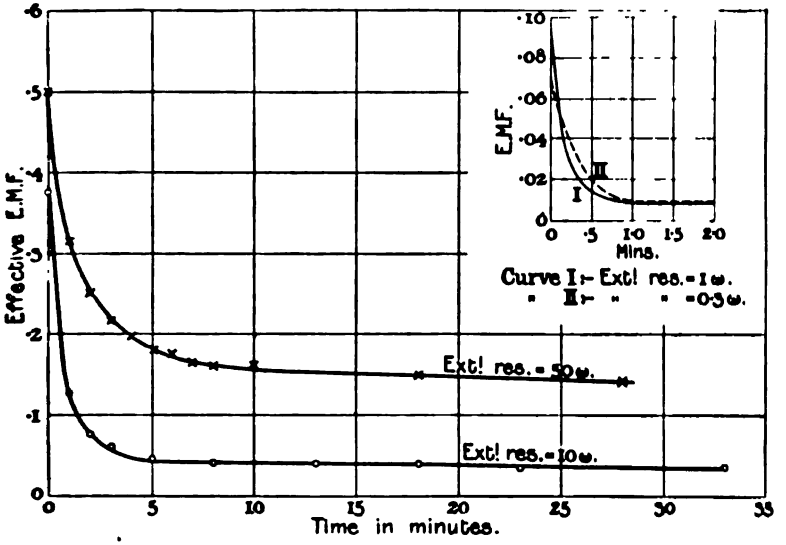


FIG. 1.

by the condenser method. The internal resistance was also repeatedly measured by a Kohlrausch bridge. From the observations the internal pressure of the cell was calculated. The plotted results are shown in Fig. 1, from which it will be seen that the pressure falls both with time and with decreasing resistance. An approximate value for the short-circuited cell was found by plotting the E.M.F. values against the external resistance and continuing the line backward to find the value for R = O. This was found to be 0·007, as shown in Fig. 2.

The use of methods in which a rotating secohmmeter commutator has been applied to obtain the open circuit voltage, and the separate measurement of the potentials of the electrodes confirm the conclusion that the E.M.F. of a galvanic couple is small. Nevertheless since the electrical resistance of the galvanic couple may be also small, currents

of sufficient magnitude will be produced which will soon bring about the corrosion of the positive member.

To return to the example. If the value of $E = 0{\cdot}006$ be assumed as the effective voltage between zinc and lead, then—

$$U = 0{\cdot}000212 \times 0{\cdot}006 = 1{\cdot}272 \times 10^{-6} \text{ gramme per second}$$
$$= 4{\cdot}60 \times 10^{-3} \text{ gramme per hour.}$$

Experimental difficulties so far have prevented a good confirmation of this number. It has been found that long-time tests are essential, and that the value of the effective voltage must be constantly measured and great care taken to avoid insulating films.

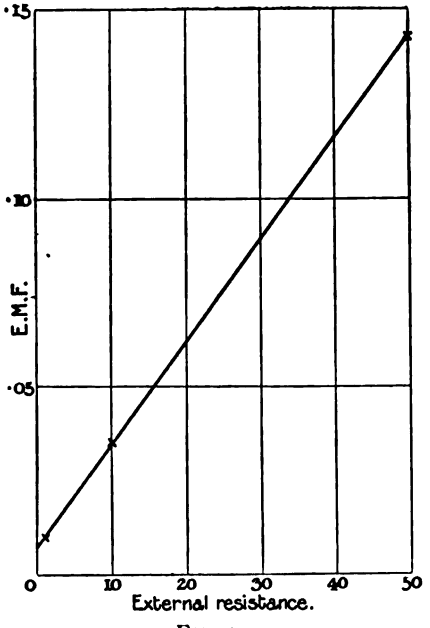


FIG. 2.

The influence of the electrolyte when in movement on the effective voltage was tested in the case of zinc and iron plates immersed in Manchester water, when (*a*) the water was stationary, and (*b*) when the water was continuously running between the plates. With 200 ohms in the circuit after 25 minutes, the voltage in case (*a*) was 0·36, in case (*b*) 0·758. Hence a galvanic couple will be more effective when the electrolyte is in movement, and this accords with practical tests.

IX.—Experiments on Galvanic Couples.

Many experiments have been made to test the actual relative rate of corrosion in the case of galvanic couples. Two examples will be given.

A. Strips of different metals were arranged in couples and securely fastened together by string. Each couple was then immersed in a separate bottle containing a solution of 10 per cent. solution of common salt. They had previously been weighed. After about 19 weeks they were removed from the solutions and then washed, any slime being removed, next dried and weighed. In a number of cases single metals were placed under the same conditions for comparison. Ten cases are quoted below :—

TABLE II.

Experiment.	Metals.	Days.	Change of Weight.
			Grammes.
1	Copper	131	0·04 gain
	Lead	„	1·28 loss
2	Ferrotype	131	0·29 loss
	Copper	„	0·01 gain
3	Copper	131	0·02 loss
	Brass Foil	„	0·15 loss
4	Copper	124	0·09 gain
	Zinc	„	0·12 loss
5	Copper	124	0·01 gain
	Aluminium	„	0·16 loss
6	Copper	124	0·02 gain
	Sheet Iron	„	0·25 loss
7	Nickel	124	0·02 gain
	Sheet Iron	„	0·20 loss
8	Ferrotype (alone)	119	0·04 loss
9	Brass Foil „	119	0·01 loss
10	Lead „	119	0·04 loss

From the above table the influence of the more positive material in protecting a more valuable metal is seen in experiments 2, 4, and 6; on the other hand, the influence of the more negative material in causing corrosion is seen in experiments 1 and 5.

B. *Experiment with Compound Metal.*—Duplex metals are now coming into use so as to unite the different properties of two metals, thus steel may be backed with copper. When such metals are in contact some care must be taken to protect the places where the metals touch, if such parts are also liable to corrosive attack. The experiment made below was performed with a copper and iron sample that had been united by a special process.

The test-piece is shown in Fig. 3. It was thoroughly cleaned and polished, then weighed and placed in 0·7 per cent. of sulphuric acid solution for 169 hours, and on being re-weighed the decrease was 1·835 grammes. The piece was now cleaned and the edges well covered with a stopping-off varnish. On again being submitted to corrosion for 169½ hours the loss was 0·49 gramme. Hence we have—

	Unprotected Edges. Lb.	Protected Edges. Lb.	Ratio of Corrosions.
Loss by corrosion per sq. in. per year ...	0·0326	0·0106	3 : 1

X.—Effect of Oxide Coatings.

Iron and steel are electro-positive to the oxides of iron. Thus bright steel tested against the same kind of steel rusted in the Manchester atmosphere during 24 hours gave 0·104 volt, and when bicycle chain link stampings were *blued* by heating in the air and then tested against bright steel stampings, the P.D. was 0·196 volt. The thin coating of magnetic oxide formed by heating or by special processes is a good protector against rust as long as the oxide film remains unbroken, but if it be partly removed (and in some cases it is very brittle) there will be a certainty of local corrosion. This effect is well shown by a corrosion test in Manchester water of bright steel against an imperfectly blued sample of the same kind of steel. The former lost 0·0173 lb. per square foot per annum, whilst the latter lost 0·0332, or about twice as much.

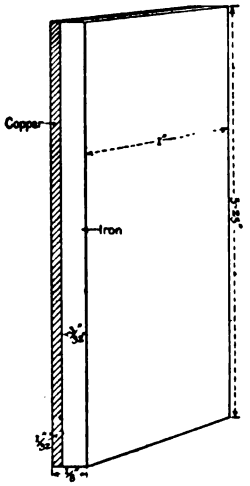


Fig. 3.

Mill-scale or black oxide is likely to produce bad cases of pitting. W. John has described the evil effect of a single particle of black oxide on a steel vessel.*

The importance of removing scale from new ironwork before the preliminary painting is obvious.

As a good preservative against rust a firm adherent coating of oxide must not be despised. We are told that the old smiths used to oil their work and heat it over a smoky fire after finishing, and thus coat it to a certain extent with an oxide of iron. This is thought to account for the preservation of examples of ironwork made 500 years ago.†

H. L. Hollis gives iron a non-corrosive film by first using it as a cathode in caustic alkali solution, and when sufficiently clean as an anode. The oxidising action which then takes place forms a protective coating. The iron is now dried and immersed for a short time in a

* *Journal of the Staffordshire Iron and Steel Institute*, p. 150, 1884.
† Discussion at the Staffordshire Iron and Steel Institute, Feb. 3, 1894.

bath of palm-oil heated to about 125° C. It is then removed and rubbed with bran to absorb the oil.*

XI.—Concentration Cells.

If a metal be immersed in a liquid so that its lower end is in a solution of greater concentration than that surrounding the upper end a P.D. results. Its value can be calculated by the method of Nernst, and although small is sufficient to cause corrosion. This is illustrated by the test detailed below.

Two thin rods of polished steel about 14 in. long were placed in two separate vessels, No. 1 containing a solution of half-saturated solution of sodium chloride, and No. 2, which was half-filled, with a saturated salt solution, on which water was carefully poured so as to fill the remainder of the vessel. After about 150 hours the loss of weight of the rods was ascertained. It was found that the rod in No. 1 had lost 0·01 gramme and was slightly corroded near the top, but the rod in No. 2—which was also corroded near the top—had lost 0·025 gramme.

Similar effects are found in the case of iron structures submerged in tidal rivers.†

XII.—Effect of Stress.

T. Andrews has investigated the effect of stress in causing a P.D. in the case of steels and found the unstrained material electro-positive. Jackson has shown that the corrodibility is increased practically according to the amount of the strain, so that a diagram plotted for stress-corrodibility is like a stress-strain graph. This effect is thought to explain cases of grooving of bridge members. The effect of stress on potential difference has been recently studied by Hambuechen and others.‡

XIII.—Corrosion Produced by Galvanic Couples.

Many examples of the disastrous effects of disregarding the principle that the more positive metal is attacked are brought under notice from time to time. Copper-bottomed ships have been the cause of legal action, as at Leghorn, where the ships and vessels lying in the harbour were found to be materially damaged by the galvanic currents set up from the copper bottoms of the yachts, electrical connections being made with the steel vessels through the ropes and hawsers which were used to make them fast to the different buoys. Damage to the ships being proved, the copper-bottomed vessels had to be removed from the harbour.§

The *Bancroft*, a steel practice cruiser of the U.S. Naval Academy, was abnormally corroded owing to the presence of the *Santee*,

* U.S. Patent 827,802.

† T. Andrews, Midland Institute of Mining and Civil Engineers: *Electrician*, vol. 26, p. 533, 1891, and *Iron*, Jan. 23, p. 71, 1891.

‡ Especially see W. H. Walker and C. Dill, *Transactions of the American Electrochemical Society*, vol. 11, p. 153, 1907.

§ *Electrochemist and Metallurgist*, vol. 3, p. 245, 1903.

a coppered wooden vessel, some 90 ft. away—both being moored by chains to a single anchor.*

The commission of engineers appointed to investigate the cause of the failure of the Tay Bridge, reported that when cast iron and wrought iron were connected by rivets in many parts of the same structure, the rivets and connecting wrought-iron work had corroded by local galvanic currents.†

An examination of the literature relating to the corrosion of boilers reveals many examples of the injurious effect of having metals in contact between which there is potential difference.

XIV.—Use of Couples in Preventing Corrosion.

Sir H. Davy endeavoured to protect copper-sheathed sea-going vessels against the action of sea-water by using strips of zinc fastened to the copper. The experiment failed in practice owing to the

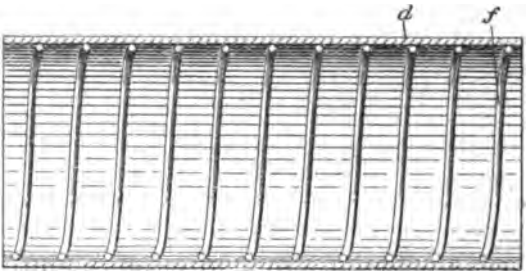


Fig. 4.

protected copper becoming covered with seaweed and shell-fish, which do not adhere to the corroded copper surface.‡

The method has been adopted in recent patents. Thus Uthemann § protects copper surfaces from the corroding action of sea-water by providing the surface with iron strips or rods placed at intervals along it, and in electrical contact with the copper, the rods having a thickness of $\frac{1}{150}$th part of the surface to be protected. This is shown applied to a copper pipe *d* used to conduct sea-water (Fig. 4). This pipe is provided with an iron helix *f* in electrical contact with the inner surface of the pipe. An electrolytic action takes place and the iron is oxidised, depositing a firmly adhering and uniform layer of oxide of iron. When the surface is flat the electro-positive material may be applied in the form of netting.

It is well recognised that the corrosion of a boiler may be mitigated by suspending in the water zinc plates in metallic connection with the

* "The Care of Steel Ships," by P. Hichborn, Chief Constructor of the U.S. Navy, *Cassier's Magazine*, vol. 8, pp. 109–112, 1895.

† *Proceedings of the Institution of Civil Engineers*, vol. 77, p. 323; vol. 82, p. 281.

‡ For an interesting account of the investigation commenced in 1823, see "The Life of Sir Humphry Davy," by J. A. Paris, vol. 2, pp. 222–282, 1831.

§ German Patent 801,489.

boiler. The zinc may be used in slabs about 1 ft. long, 6 in. wide, and 1 in. thick in the proportion of one slab to each 50 sq. ft. of heating surface in the case of marine boilers.

The corrosion of sheet metal radiators used for steam and hot-water

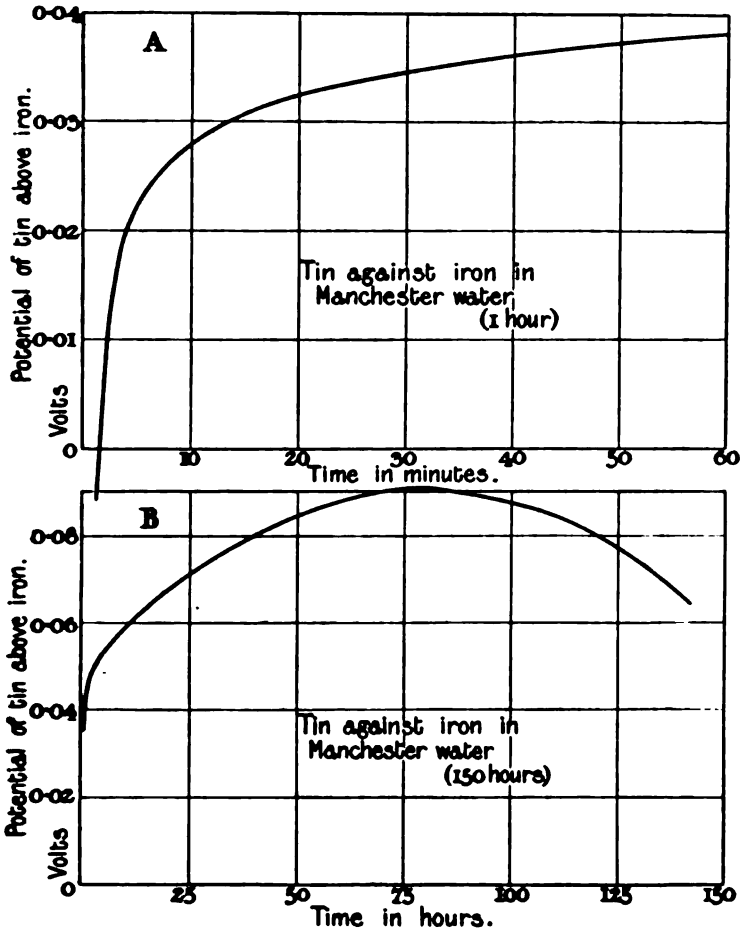


FIG. 5.

heating is avoided by Kinnear by the introduction of zinc. Various forms of suspension arrangements are shown in his specifications.*

Considerable trouble has arisen with copper or Muntz metal surfaces used as tubes in condensers. When zinc is used as a protector it is necessary to renew the zinc frequently, owing to its liability to

* U.S. Patent 752,844, 1904.

disintegration. According to a recent patent, aluminium is said to do better than zinc, presenting always a clean surface and being less liable to disintegration.*

It may be stated in a general way that experience has established that zinc is the best protector of iron, hence the importance of the so-called process of galvanising.

Tin is an inferior metal owing to its nearness to iron in the E.M.F. series. The change of the P.D. of tin against iron in Manchester water is shown in Fig. 5. With a resistance of 10,000 ohms in circuit the tin was at first positive but soon became negative. After 80 hours the P.D. was 0·09, but rose to 0·42 on breaking the circuit. The effect of 150 hours was to bring the voltage to 0·065.

XV.—Multiple Galvanic Couples.

In 1872 J. H. Gladstone and A. Tribe communicated the fact to the Royal Society that zinc on which an electro-negative metal was deposited in a spongy state decomposes water at the ordinary temperature. Since copper was found to be the most suitable metal to associate with zinc, they termed the arrangement a "copper-zinc couple," which has been of great service in chemical research.† It was subsequently found that effective couples could be prepared by using mixtures of zinc filings and copper powders.‡

Their experiments confirm the conclusion that in these arrangements "we have minute pieces of metal forming myriads of currents in which the resistance of the binary compound is reduced to a minimum as it washes the very points of contact of the metals." To form a good couple other circumstances beside the P.D. of its elements must be taken into account. It is essential that the negative material should adhere well to the zinc, and if heat is employed to form the couple there must be no alloying of the metals.

The example given below of the action of galvanic couples has been obtained for me by Mr. F. S. Sinnatt. Powdered zinc, which had been put through a mesh of 20 to the inch, was treated with a 5 per cent. solution of copper sulphate and then thoroughly washed free from copper dust. The dried powder was employed to prepare hydrogen by dissolving it in dilute sulphuric acid. The apparatus employed consisted of a litre flask placed within a large water bath through which water continually flowed. The evolved hydrogen was collected in successive 100 c.c. quantities by the use of two burettes, the pressure being kept constant through the experiment by hand adjustment. Three different strengths of acids were employed: (1) 5 per cent., (2) 15 per cent., and (3) 30 per cent. Eight grammes of copper-zinc were used in each experiment, which were dissolved in 500 c.c. of solution. An experiment was also made with powdered zinc alone in 5 per cent. acid. An examination of the curves (Fig. 6)

* *Mechanical Engineer*, vol. 17. p, 174, 1906.
† *Journal of the Chemical Society*, vol. 31, p. 561, 1877.
‡ *Ibid.*, vol. 35, p. 567, 1879.

will show that at first the rate of evolution rapidly rises, probably owing to the back-pressure taking time to attain its maximum, then follows a period of maximum velocity, which is followed by an after-period in which the rate gets gradually less as the little batteries shut down. The velocity is greater as the percentage of acid increases, the 30 per cent. especially showing a very high velocity. The rate of the solution

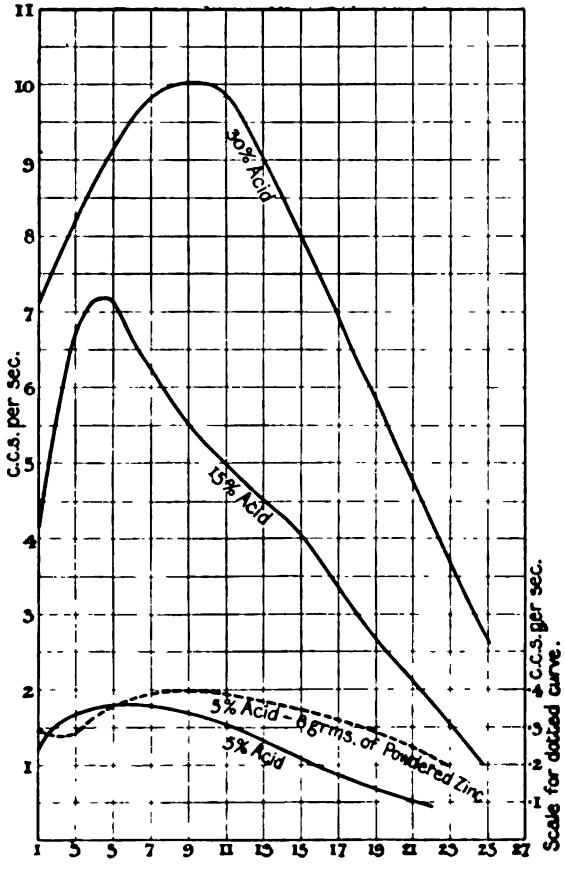


FIG. 6.

of the zinc powder, which was of fairly pure material, is about $\frac{1}{10}$th of the copper-zinc couple with the same strength of acid. The comparative maximum rates of the couples in the three strengths of acid are much greater than the relative conductivities of the three solutions, their order being as 2 : 3 : 10 approximately, whereas the order of the maximum velocities is 2 : 8·5 : 11·8. Electrolytic data for the complete analysis of the curves are not yet available.

XVI.—Self or Chemical Corrosion.

The provisional hypothesis mentioned in the introduction to this paper, that chemical changes are electrolytic, dates back from the time of Davy, but in spite of the great progress of physical and electrochemistry since his time, our knowledge of the mechanism of the processes that are involved in the solution of metals is very incomplete. The familiar example of the solution of zinc in dilute sulphuric acid was investigated by De la Rive in 1830;* who measured the rate of evolution of hydrogen with acids of different strengths. He found that the rate of evolution of the gas was greater with commercial than with redistilled zinc, but by the addition of tin, lead, copper, and iron to the pure zinc the rate was increased. He showed that with acid of maximum electrical conductivity the rate was also a maximum. These experiments point to the existence of a great number of galvanic couples with an E.M.F. depending on the metals in contact, giving a current in each case varying with the conductivity of the electrolyte. With ordinary commercial zinc the rate of solution is found to differ much with samples that are apparently of the same kind. This is attributed to the irregular distribution of the lead or other electronegative metals present as impurities.† That local currents are the determining factor in the solution of metals is confirmed by the work of T. Ericson Aurén and W. Palmaer,‡ yet a different way of viewing the matter has been developed in recent physical chemistry researches, the *velocity reactions in heterogeneous systems* being deduced from a number of physical conditions. Thus when the solvent is in movement the reaction velocity will be proportional to the rate of movement of the gliding liquid and will depend on some function of the surface.§ Again, it must be admitted that the velocity of reaction in the case of the solution of metals seems in some cases not to depend on the conductivity of the solvent.‖ Leaving future investigations to furnish a more complete explanation, the simple electrolytic hypothesis seems in accord with the chief facts of corrosion. Hence to corrode a metal we require a potential difference between its parts and a suitable electrolyte. The P.D. may be produced either by a physical or chemical difference in the constituent parts. A variation in the crystalline nature of the particles may, for example, be a sufficient cause of potential difference, or parts may be amorphous and other parts crystalline.¶

XVII.—The Corrosion of Associated Metals.

If an electrode consist of a *mechanical mixture* of metals the potential of the electrode will be determined by the most positive constituent. For instance, a mixture of copper and zinc will give the

* *Poggendorff's Annalen*, vol. 19, p. 221, 1830.

† E. Divers and T. Shimidzu, *Journal of the Chemical Society*, vol. 47, p. 597, 1885.

‡ *Zeitschrift für Physikalische Chemie*, vol. 39, p. 1, 1902, and vol. 45, p. 182, 1903.

§ See L. Bruner and S. Tolloczko, *Zeitschrift für Anorganischie Chemie*, vol. 35, part 1, p. 23, 1903; E. Brunner, *Zeitschrift für Physikalische Chemie*, vol. 47, p. 56, 1904.

‖ See H. Patten, *Journal of Physical Chemistry*, vol. 7, p. 153, 1903; and J. H. Matthews, *Ibid.*, vol. 9, p. 641, 1905.

¶ See C. E. Fawsitt, *Proceedings of the Royal Society of Edinburgh*, vol. 26, p. 2, 1905–6.

pressure of the zinc, and this holds good as long as 0·2 per cent. of the zinc is present.*

If the metals form *a solid solution* then the alloy is found to be less positive than the most positive of the constituents, and may even be less corrodible than either of them. When the alloy itself corrodes the more positive metal is likely to be attacked first. Again, the metals may form a *chemical compound* with each other, and when corroded the constituents may pass into solution together. These general principles explain the decay of alloys. Thus brass when exposed to the corrosion of sea-water undergoes "de-zinkification." Brass has a duplex structure consisting of two constituents, one being richer in zinc than the other, and Arnold has shown that the final effect of galvanic corrosion is for both to lose their zinc.† Interesting examples of the same action are recorded by Milton and Larke.‡

An important example is furnished by Muntz's metal (an alloy of copper and zinc), which is employed as a sheathing for the protection of the woodwork of sea-going vessels against the action of mollusca and algæ. Its action depends upon its slow solution by sea-water, and so rendering its surface poisonous to marine growth.§ It has been shown that this alloy consists of two kinds of crystals, the α and β. The percentage of zinc in the latter being the greater they are positive to the α crystals. They accordingly dissolve and leave a network of α crystals, which on breaking up falls into the solution and dissolves.¶

The method of anodic corrosion has been applied in an interesting way to the examination of the alloys of copper and tin. The apparatus used by B. E. Curry** consisted of a number of cells in series with platinum cathodes and bronze test-pieces as anodes which were kept in rotation during the test. The curves, Figs. 7 and 8, show the results in the case of a 7 per cent. solution of sodium sulphate and a 7 per cent. sodium carbonate solution. The ϵ bronzes undergo little change and tend to become passive. The results of electrolytic corrosion seem to be the same as the effect of ordinary or chemical corrosion, but whilst the electrolytic method can be applied in a few hours, tests of ordinary corrosion require many weeks or months to obtain a satisfactory result. Further researches are required before we can be certain that a complete connection can be assumed between the two methods.

A start has been made in the application of the method at the School of Technology to alloys of practical importance.

* Laurie, *Journal of the Chemical Society*, vol. 53, p. 104, 1888.
† *Engineer*, vol. 85, p. 363, 1898.
‡ *Proceedings of the Institution of Civil Engineers*, vol. 154, p. 138, 1903.
§ J. A. Rhodin, *Transactions of the Faraday Society*, vol. 1, p. 127, 1907.
‖ Shepherd, *Journal of Physical Chemistry*, vol. 8, p. 421, 1904.
¶ A. K. Huntington, *Transactions of the Faraday Society*, vol. 1, p. 134.
** *Transactions of the American Electrochemical Society*, vol. 9, p. 173, 1906; also A. T. Lincoln on "The Electrolytic Corrosion of Brasses," *ibid.*, vol. 11, p. 43, 1907; W. S. Rowland, "Electrolytic Corrosion of Cu-Al Alloys," *Journal of Physical Chemistry*, vol. 12, p. 180, 1908.

XVIII.—The Corrosion of Iron and Steel.

The experiments of Crace Calvert* showed that for the rusting of iron three things are essential: oxygen, water, and carbon dioxide. All three are essential. Bright iron may be sealed up in water in the presence of air for many years, but admit the smallest trace of carbon dioxide, and then rusting rapidly proceeds. The ferrous carbonate produced is oxidised by the oxygen to form ferric hydrate with the liberation of carbon dioxide, which latter is retained in solution and attacks a fresh portion of the iron. The action is thus cyclic, and a small quantity of carbon dioxide will create a large quantity of rust. The theory has received recent confirmation by the experiments of G. T. Moody,† but Dunstan, Jowett, and Goulding‡ believe that hydroxyl is the effective agent. It is known that iron will not rust in an alkaline solution, and much of the earlier work has been thrown in

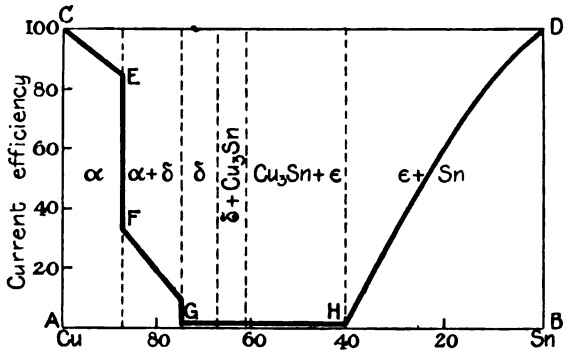


FIG. 7.

doubt by the use of glass vessels which may have given up sufficient alkali to inhibit rusting. This is the view of Walker, Cederholm, and Bent.§ They found that when Jena glass is used iron will rust in the presence of carbon dioxide free water. J. N. Friend‖ also finds that oxygen and water alone will rust the impurer kinds of iron.

There, however, can be little doubt that the carbon dioxide of the air is an important factor in causing rust. Its solution in water will provide the necessary electrolyte to give a current with the aid of the anodic and cathodic particles in the iron. The presence of the positive and negative areas may be revealed by the use of a solution containing a mixture of phenolpthalein and potassium ferricyanide. When a piece of bright steel is placed in the indicator blue and red patches and zones of opposite polarity will be produced.¶ Where the

* *Memoirs of the Manchester Lit. Phil. Society*, vol. 5, p. 104, 1871.
† *Journal of the Chemical Society*, vol. 89, p. 720, 1906.
‡ *Ibid.*, vol. 87, p. 1548, 1905.
§ *Journal of the American Chemical Society*, vol. 29, p. 1251, 1907.
‖ *Nature*, vol. 74, p. 540, 1906.
¶ W. H. Walker finds that it is a good plan to stiffen the combined reagent with gelatine or agar-agar jelly.

iron dissolves a blue tint is seen, and at the cathode parts the liberated alkali produces the well-known pink reaction.

In revealing the polarity differences the microscope is useful. I find that when a highly polished piece of steel is etched under the microscope, by the use of acid, hydrogen can be seen escaping in the form of small bubbles from the electro-negative areas. There seems room to extend the use of the microscope to the examination of the corrosion conditions.

The corrosion of iron by atmospheric influences presents an important difference to the case of the action of acids, for the product of corrosion being soluble, the salt diffuses away when the metal is at rest, or is removed as fast as it is formed when the metal is washed by a moving solution, whereas the rust remains on the metal and creates with the iron a galvanic couple. This aspect of rusting has been

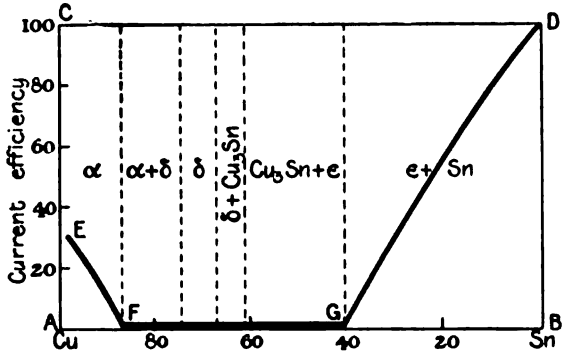


FIG. 8.

especially dealt with by Mugdan.* When once a speck of rust is formed at a centre of infection the corruption continues with increasing rapidity, and is aided by the increasing bulk of the rust, which will help to retain the electrolyte.

For reasons of an electro-chemical kind that are now fairly well understood, solutions of soda and potash and the carbonates of these metals, and in a less degree solutions of lime, protect iron and steel against corrosion. To this may be added chromic acid, and a number of other compounds. This fact deserves to be better known. Steel may be preserved from rusting for any length of time when placed in a solution of soda.

The presence of sulphur dioxide from the burning of coal and coal-gas may altogether change the nature of the decay of iron. The sulphur dioxide is readily oxidised in the presence of moisture to sulphuric acid, which will dissolve iron to form ferrous sulphate. This

* *Zeitschrift für Elektrochemie*, vol. 9, p. 442, 1903. A. S. Cushman, in a Bulletin of the U.S. Board of Agriculture, has also developed the electro-chemical theory of rusting: *Transactions of the American Electrochemical Society*, vol. 12, p. 403, 1907.

latter will then be oxidised to a basic ferric sulphate, which is an insoluble brown substance. Ironwork in tunnels on railways (not yet electrified) well exhibits the power of sulphur and other compounds in causing rapid destruction.*

We are indebted to a number of engineers who have made long time tests on the corrosion of iron and steel. From the mass of evidence published the task of arriving at any definite conclusions as to the relative corrodibility of the different grades of iron and steel is one of difficulty. Not much useful purpose would be served by quoting the earlier results that were obtained before the development of the science of metallography. I will only refer to some of the recent work which supports the galvanic theory of corrosion.

The Seventh Report of the Alloys Research Committee dealing with steels containing nickel and manganese confirms the views of the importance of structure in determining corrosion. It was found that alloys containing *pearlite* were the most readily attacked, with *polyhedral* the least attacked, whilst those with *martensite* were intermediate in their corrodibility. This is explained by the P.D.'s set up in the complex structure of the pearlite, whereas the polyhedral materials are more homogeneous and less liable to attack. It was also found that as the percentage of nickel was increased the alloy was less corrodible.† According to Dumas nickel steels present the most perfect examples of solid solutions, no segregation having been detected by the microscope.‡

These results confirm those of the experiments made by Diegel in the harbour of Kiel.

Considerable assistance may be given by anodic etching to the examination of the structure of steel. J. O. Arnold has found that with an electrolyte of dilute hydrochloric acid, and using an anode of supersaturated steel containing 1·47 per cent. of carbon, pearlite carbide is dissolved but cementite is little acted upon, whereas with a saturated steel practically the whole of the pearlite is unacted upon.§

Generally it may be said that the main constituents of steel can be classified into electro-positive and electro-negative groups, and the distinction can be revealed by the use of etching reagents.‖

With reference to wrought iron, all experiments confirm that the finer its quality and the more perfectly uniform its texture the slower and the more regular is its corrosion.

XIX.—The Corrosion of Lead.

Lead is a very durable metal as far as atmospheric corrosion is concerned, but its liability to corrode by the action of the salts in soil, plaster, ashes, and refuse, etc., presents problems to the electrical engineer which cannot be lightly regarded. It is chiefly with the

* See A. H. Sexton, "The Corrosion and Protection of Metals."
† *Proceedings of the Institution of Mechanical Engineers*, pp. 851–1041, 1905.
‡ *Journal of the Iron and Steel Institute*, vol. 68, p. 255, 1905.
§ *Proceedings of the Institution of Civil Engineers*, vol. 123, p. 127, 1895.
‖ Arnold and McWilliam, *Engineering*, vol. 80, p. 422, 1905.

smaller sizes of lead-covered cables that the trouble is noticeable. Many examples can be given of the destructive action of the moisture of walls and the action of organic acids produced by decaying matter.*

Lead-covered cables are, of course, especially liable to mechanical injury, and probably this is the chief cause of faults. The whole subject has already been brought under the notice of the Institution by Atkinson and Beaver, and they conclude that "extreme care is necessary to avoid conditions which tend to produce lead faults," and they think "that the use of lead-covered cables on large networks carrying heavy currents will probably be limited in the future." †

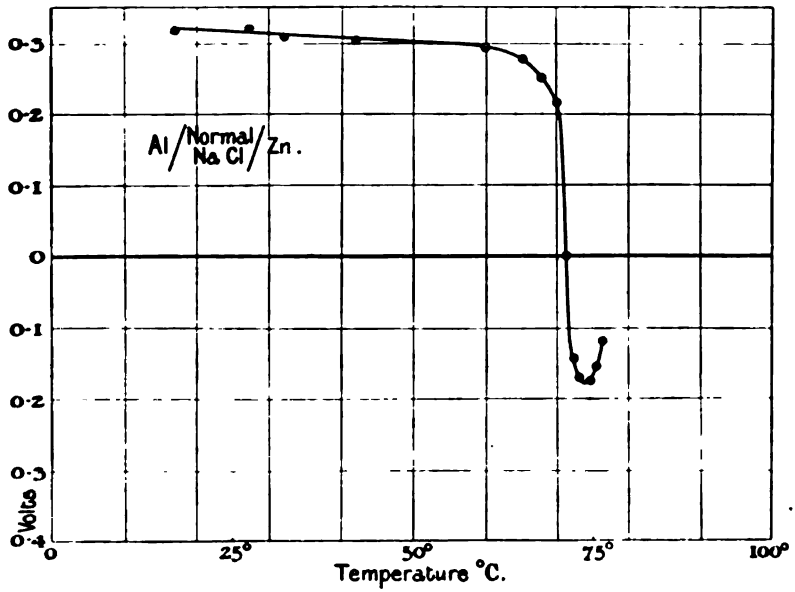


FIG. 9.

Lead being electro-positive to copper and brass the contact of the two must be avoided. The same applies when the copper is tinned. The use of solder always introduces risks if a suitable electrolyte is present, hence the wisdom of the electrical instrument maker in forbidding the use of soldering fluids which contain metallic salts. On the other hand, lead is electro-negative to iron, and should not be used for fixing iron in stonework. These facts are well known, but they are disregarded only too frequently.

Galvanic action has been set up between lead and tinned copper wires in the presence of moisture, causing the lead coverings to be

* See D. S. Munro, *Electrical Review*, vol. 55, p. 693, 1904.

† *Electrician*, vol. 54, p. 702, 1905. Also see "Cables: The Usual Causes of Trouble and Failure," by C. J. Beaver, paper read before the Electrical Contractors' Association, October 24, 1905.

corroded through in about two years. In this case the lead had been applied externally directly over the outer conductor.*

XX.—The Corrosion of Aluminium.

The immunity that aluminium has from corrosive attack by the atmosphere is largely due to the remarkable film of oxide that is present on its surface which gives it some of the properties of a noble metal. Under the action of a burnisher the film is rubbed off the surface, and the metal is raised to a higher polish; "the instant the burnishing tool leaves a given point on the surface of the metal a film of oxide forms, and, as it were, fixes the surface of the metal at a higher degree of polish."† The film when intact makes the metal more electro-negative than it should be and, owing to the ease of its formation, renders it difficult rightly to place the metal in the electromotive series.

The following table shows its probable position as tested against a calomel electrode at ordinary temperatures with normal solutions‡ :—

Magnesium... ...	— 1·774	
Aluminium	— 1·559	
Manganese	— 1·358	
Zinc	— 1·053	
Cadmium	— 0·703	
Iron	— 0·940	(approximate)
Nickel	— 0·880	(„)
Tin	< — 0·475	
Lead	— 0·431	
Hydrogen	— 0·283	
Copper	+ 0·046	
Platinum	+ 0·580	
Oxygen	+ 0·110	

Thus the position of aluminium is above zinc, but it will be found that on testing the P.D. between aluminium and zinc in sodium chloride solution that zinc is the more positive metal, and that in a galvanic couple of the two metals zinc is the metal to be corroded. I have made some interesting observations on the change as the solution is heated. The P.D. in open current was obtained between zinc and an aluminium calorimeter in which was contained a normal solution of sodium chloride which was gradually heated. At first the zinc was the positive metal, but at about 70° C. the P.D. changed sign, as shown in Fig. 9. This remarkable change is explained by the action of hot salt solution on aluminium and zinc. This has been studied by Watson Smith.§ He finds that aluminium is attacked by hot and moderately strong solutions of sodium chloride. The action, although small (15·714 grammes of aluminium foil only lost 0·024 gramme

* Atkinson and Beaver, *Electrician*, vol. 54, p. 702, 1905.

† W. M. Morrison, *Journal of the Institution of Electrical Engineers*, vol. 31, p. 400, 1902.

‡ Max le Blanc, "Electro-Chemistry," p. 248, 1907.

§ *Journal of the Society of Chemical Industry*, vol. 23, p. 475, 1904.

in four days), is sufficient to cause the solution of the electro-negative film. The film, on cooling the liquid, reforms. It is interesting that the limit of temperature between the formation of the film and its disappearance is so close. Zinc is more attacked by the hot salt solution than the aluminium, but the product of the reaction is non-adherent to the metal. To verify that the chief effect of change was at the aluminium the P.D. of each electrode was tested by the use of cadmium as a separate or standard electrode. Observations were also made with Manchester tap water. The change of the P.D. on heating and then cooling is shown in Fig. 10, which exhibits a peculiar kind of hysteresis.

A more durable film can be formed electrolytically by making the

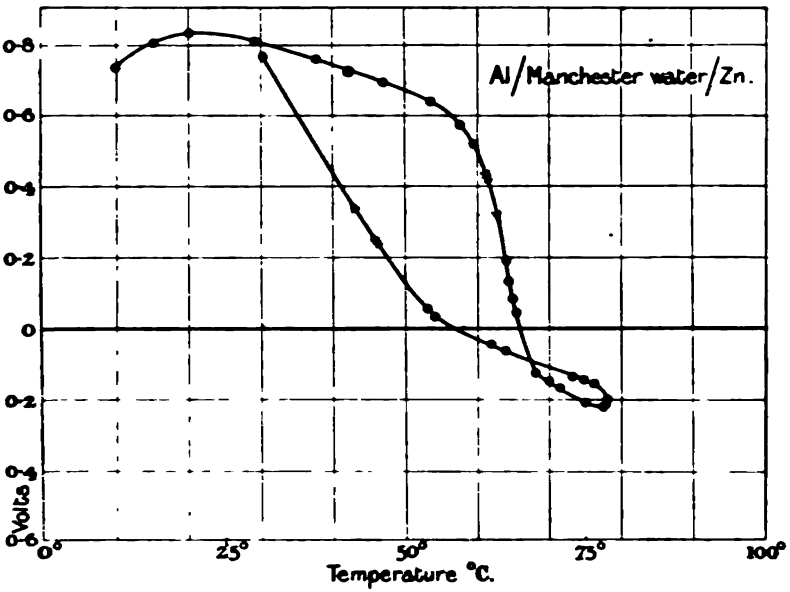


FIG. 10.

metal an anode in phosphate solutions. Aluminium protected in this way is better able to stand the action of hydrochloric acid. This is shown by Fig. 11,* which gives the rate of solution of aluminium by measuring the rapidity of the evolution of hydrogen when the metal is attacked by the acid, when (Curve I.) no film has been formed, and (Curve II.) when the metal had been protected by a film formed at 125 volts.

In spite of the protective film, aluminium remains electro-positive to iron and copper, hence its contact with these metals must be avoided.† Since it is difficult to solder aluminium, if a mechanical

* W. R. Mott, *Electrochemical Industry*, vol. 2, p. 120, 1904.
† W. M. Morrison, *Electrician*, vol. 48, p. 389, 27, 1901.

joint is made, it is necessary that it should be also of aluminium, otherwise a detrimental electrolytic action may be expected.*

When aluminium is in industrial use its decay may be slow or rapid, according to the purity of the metal. This has, unfortunately, been disregarded in a number of tests, and has led to the unjust condemnation of the metal; still it must be admitted that since aluminium may lose its protective film, the advice of Moissan (who was a strong advocate for the use of the metal), that "chaque application de ce metal demande une étude spéciale, longue et délicate," is wise.†

I have not been able to get much real information on the durability of bare aluminium transmission lines. J. B. C. Kershaw found that the

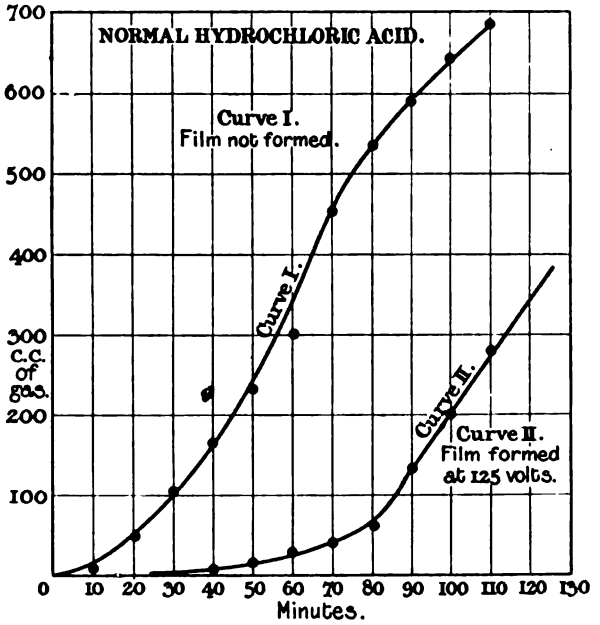


FIG. 11.—Action of Hydrochloric Acid.

samples tested by him were not suitable for overhead work near the coast.‡ When light aluminium alloys are used the presence of copper (say 2 per cent.) is injurious to the life of the wire.§

Aluminium paint is coming largely into use. As it will stand a high temperature it is useful for radiators, etc. For the ironwork of laboratories the experience at the Manchester School of Technology has been very satisfactory. The main matter of importance is that the iron should be well cleaned before the paint is applied.

* *Electrical Review* (N.Y.), vol. 35, p. 203, 1899: *Electrical Review* (London), vol. 45, p. 586, 1899.

† *Comptes Rendus*, vol. 128, p. 900, 1899.

‡ *Journal of the Institution of Electrical Engineers*, vol. 30, p. 353, 1901.

§ Wilson, *ibid.*, vol. 31, p. 322, 1902.

The oxide film being of an insulating character, aluminium wire without any other covering may be used for winding coils.* The film action gives us the rectifier, the condenser, the controller, and the lightning protector.

In the use of aluminium for the building of boats, it is essential that only metal which has become homogeneous by means of a series of

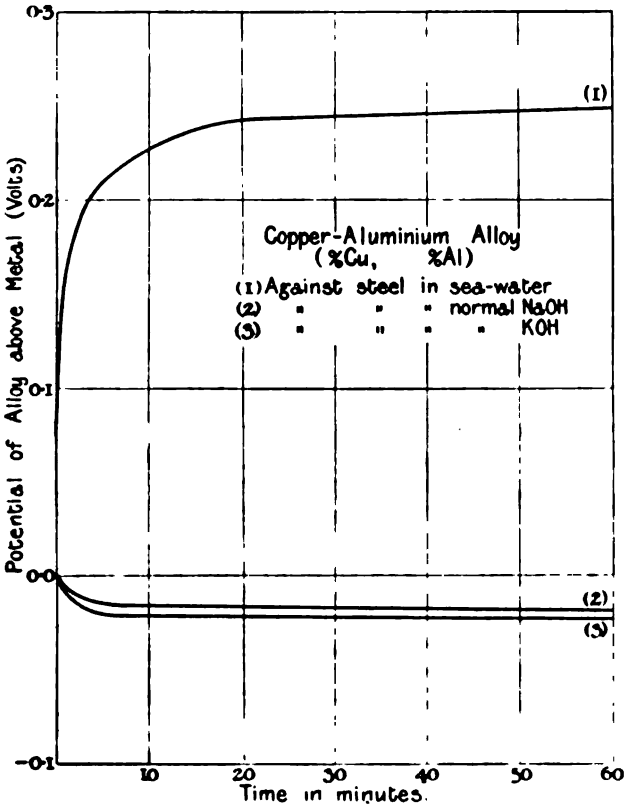


FIG. 12.

re-meltings should be used.† The torpedo-boat *La Foudre* quickly went to pieces since sufficient care had not been taken to use homogeneous metal.

It is still more important to avoid the contact of other metals. The freeboard plates of the *Defender* were made of a nickel-aluminium

* *Elektrische Bahnen und Betriebe*, vol. 4, p. 633, 1906; and *Electrician*, vol. 58, p. 237, 1906.

† Minet's "Production of Aluminium and its Industrial Use," p. 199, 1905.

alloy and were fastened with steel rivets to the manganese-bronze hull and were badly corroded.*

The eighth report of the Alloys Research Committee of the Institution of Mechanical Engineers shows that rich copper aluminium alloys do not corrode when in conjunction with mild steel in sea-water. To confirm this by potential difference tests, Professor H. C. H. Carpenter kindly lent me a series of alloys that had been used in the research. It was found that although the percentage of aluminium varied from 0·2 to 13 per cent., there was little potential difference between them when tested in various liquids, with 10,000 ohms in circuit. Tests with one containing 13 per cent. aluminium are shown in Fig. 12, which show:

(1) That steel is electro-positive against the alloy in sea-water. At the end of 60 hours the P.D. was 0·25 volt.
(2) and (3) That steel is electro-negative to alloy in normal caustic soda or potash, the P.D. being about 0·02 volt.

XXI.—Electrolysis due to Stray Currents.

To those who have watched the progress of the use of the uninsulated returns for traction purposes the word "electrolysis" is reminiscent of many a controversy in which the opponents of electrical engineers have been those in charge of certain vested interests. Fortunately the delay in establishing electrical traction in this country under wise conditions enables one to say that our gas and water pipes, as well as our telephone, telegraph, electric light, and traction cables are depreciated little, if at all, by stray currents. Happy is the land where the bonds are good, the positive and negative feeders rightly calculated, and all is under the watchful care of a paternal Board of Trade. This is not the country where one can study electrolysis due to stray currents. The voltmeter and the coulombmeter must be taken to the United States or to Germany, where there will be readings worth the taking.

Reports of electrolytic injury to pipes come from all parts of the United States.† S. Sheldon has given before the American Institute of Electrical Engineers some interesting information regarding Brooklyn, where the P.D. between the rails and hydrants, and the rails and gas mains, may be as high as 25 volts. Between the ends of Brooklyn Bridge a difference of 20 volts has been recorded.‡ Gas services and water-service pipes have been extensively corroded. Cast-iron mains, on the other hand, have been to a large extent immune owing to their siliceous coating. It is mainly at the joints that trouble is found. Measurements made by L. T. Blake § upon a line of 6-in. cast-iron water mains, which had been in service for thirteen years, in the case of

* J. A. Steinmetz, *Transactions of the American Electrochemical Society*, vol. 3, p. 217, 1903.

† D. H. Maury, Paper read before the American Water Works Association. Abstract in *Electrician*, vol. 45, p. 812, 1900.

‡ *Electrical Review*, vol. 47, p. 206, 1900. § *Electrician*, vol. 44, p. 339, 1899.

a length of 339 ft. having nineteen joints gave a resistance of the joints as 88·2 per cent. of the total resistance of the pipe. Electrolytic pittings were found on many sections near the joints, but only on the positive where the stray current was shunted round the joint. The asphaltum coating of the pipe is not a sufficient protection, for under the coating —although apparently intact—pittings are found.

C. E. Phelps* records that 20 per cent. of the whole faults in underground cables at Baltimore during seven years were due to electrolytic action.

With reference to Germany, the work of the Deutscher Verein von Gas und Wasserfachmännern has given us exact information. Table III. on the next page includes some of the electrical measurements.†

Taking H. F. Parshall's statement‡ that owing to the great surface of the track and the good conductivity of the earth about one-third of the return current passes through the earth, the question must be asked what proportion of this do neighbouring pipes carry. The experimental answer is that as a rule such conductors carry little or no current when the line is worked under Board of Trade conditions. The smallness of this current through cast-iron pipes has been verified by Claude.§ The current through the pipe is not only small, but only a small proportion of it causes electrolytic effect. Herrick‖ shows that the corrosion of iron only reached 3·5 per cent. of the theoretical loss. The researches of the German investigators have thrown light on the reason of these small losses. The details will be found in two important papers by Haber,¶ first in conjunction with Goldschmidt and then with Liese. Great importance is attached to whether the iron is active or passive, the corrosion of the iron being general represented by $(1 - x)$ 1·024 grammes per hour. When $x = 0$, then the iron is completely active, but when $x = 1$ we have total passivity.

The change from the active to the passive state (as shown by the experiments described in this paper) depends on the current density and the nature of the salts in the soil, the most important being the nitrates. Iron in an alkaline carbonate becomes passive, but in the presence of free carbonic acid it is attacked; on the other hand, the chlorides are always likely to produce corrosion. Generally it is found that the earth conducts electrolytically and not metallically, and its specific conductivity can be calculated from the concentration of the salt solution present in the soil. When the iron is active electrolysis is produced with just sufficient voltage to overcome the hydrogen at the cathode, but since the air of soils acts as a depolariser, this voltage will be small. Finally it is decided that a P.D. of 1 volt will not, as a rule, be harmful.

* *Electrician*, vol. 59, p. 524, 1907.
† *Electrician*, vol. 55, p. 736, 1905, and vol. 57, p. 533, 1906.
‡ *Journal of the Institution of Electrical Engineers*, vol. 27, p. 440, 1898.
§ *Engineering*, vol. 71, p. 620, 1901.
‖ *Street Railway Journal*, vol. 16, p. 396, May, 1900.
¶ *Zeitschrift für Electrochemie*, vol. 12, pp. 49 and 889, 1906.

TABLE III.—RESULTS OF MEASUREMENTS IN RAILS AND PIPES.

	Town	P.D. between Pipes and Rails.				Fall in Volts per Kilometre along				Current in Pipes.		P.D. between Return Conductors.	Total Fall of Volts in Network.	
		Pipe +		Pipe −		Rails.		Pipes.					Rails.	Pipes.
		Max. Volts.	Mean Volts.	Max. Volts.	Mean Volts.	Max. Volts.	Mean Volts.	Max. Volts.	Mean Volts.	Max. Amps.	Mean Amps.	Mean Volts.	Mean Volts.	Mean Volts.
1	Strassburg	2·8	2·2	11·5	4·0	—	3·3	—	0·3	1·0	0·7	about 4·0	about 8·0	about 1·5
2	Dresden	3·3	2·6	3·2	1·8	—	5·6	—	1·8	6·0	4·5	about 5·0	about 8·0	about 3·5
3	Hamburg	0·8	0·4	1·6	0·8	—	—	—	< 0·1	—	< 0·1	0·7	1·5	< 0·5
4	Freiburg	2·0	1·0	2·0	0·6	2·2	1·3	0·7	0·4	—	< 1·0	1·2	2·0	< 1·0
5	Erfurt	5·0	3·5	1·8	1·2	5·8	3·3	1·4	0·9	6·8	4·0	4·1	7·0	2·0
6	Stuttgart	—	—	3·5	1·5	2·9	1·6	24·0	14·0	1·2	0·8	1·8	2·0	2·0
7	Leipzig (a)	8·0	5·5	2·3	1·2	10·0	8·3	2·2	1·8	1·6	1·3	3·0	8·5	4·0
	(b)	1·4	1·1			7·0	6·0					4·0	5·5	
8	Liegnitz	4·0	2·5	1·9	0·8	8·5	5·0	9·2	5·0	3·3	2·5	6·0	6·5	3·0
9	Danzig	2·6	2·0	6·0	2·5	4·9	3·2	5·8	3·5	7·2	5·0	0·7	6·5	3·

NOTES.

STRASSBURG.—Marked corrosion of iron, gas, and water pipes in danger areas, and when soil unfavourable.

DRESDEN.—Frequent corrosion in the lead pipes which cross the rails in the danger area.

HAMBURG.—*After introduction of insulated return*, no corrosion.

FREIBURG.—No corrosion.

ERFURT.—Marked corrosion of iron, gas, and water pipes in danger areas.

STUTTGART.—Corrosion particularly noticed *in the neighbourhood of uninsulated returns.*

LEIPZIG.—Lead pipes frequently attacked in the danger zone.

LIEGNITZ AND DANZIG.—Lead and iron pipes corroded in danger area.

A serious aspect of electrolysis due to stray currents is the possibility of causing the solution of lead in drinking water. A case of "Plumbism due to Electrolysis" is said to have taken place in the district of the South Hants Waterworks Company, and is discussed by B. Latham,* a difference of 1·8 volts between an earth return and a lead water pipe being the possible cause of the trouble. This conclusion is doubted by A. H. Dykes.†

Fortunately such cases are very rare, and a little consideration will show that the conditions for electrolysis to produce corrosion *within* a pipe must be altogether exceptional. If this arises it must be at the joints. If these are made in a lead pipe the resistance should be low. To confirm this three wiped joints were made in a length of 5 ft. of pipe. Using the fall of pressure method to find the resistance of the jointed pipe and a pipe of the same kind which had not been jointed the following results have been obtained :—

External diameter of pipe = 0·825 in.
Inside diameter of pipe = 0·500 in.

Currents of 0·9 to 12·6 amperes were passed through the unjointed pipe and voltage drop was taken over 5 ft. length.

Average resistance = $1{\cdot}42 \times 10^{-3}$ ohms.
Measurements of the same kind taken with the jointed pipe gave average resistance = $1{\cdot}37 \times 10^{-3}$ ohms.
Lowering of the resistance due to the joints, $0{\cdot}05 \times 10^{-3}$ ohms.
The specific resistance of the plain pipe was $0{\cdot}204 \times 10^{-4}$ ohms per cm. cube.

It is thus seen that the plumber's joint when well made lowers the resistance of the pipe.

It is sometimes imagined that electricity passing through the pipe can also pass through the contained water. This is very improbable.

Take the case of the above pipe filled with a solution as good an electrical conductor as a 5 per cent. salt solution, then the resistance of the liquid filling the pipe will be 1,830 ohms. If, then, a current of 1 ampere divides between the pipe and the water for twelve hours, it may be calculated that 0·0000337 gramme of lead will be dissolved.

Where cases of plumbism are announced as due to electrolysis, the plumbo-solvency of the water should be directly tested. Certain waters from moorland sources are especially open to suspicion. A. C. Houston has shown that such waters may be acid and then have the power of dissolving lead.‡

* *Electrician*, vol. 56, p. 398, 1905–6.
† *Ibid.*, vol. 56, p. 523, 1906.
‡ Report of the Local Government Board, 1893–4. Supplement containing the report on the causes of lead poisoning. The corrosion of lead has also been studied by Paul, Ohlmüller, Heise, and Auberbach. *Zeitschrift für Elektrochemie*, vol. 12, p. 428, 1902. Also see Carnelley and Frew, *Electrician*, vol. 21, p. 583, 1888. Professor J. Radcliffe informs me that the eroding action of water passing through pipes, especially when the velocity is high, is receiving the attention of sanitary engineers. The scouring action may result in the loosening of deposits of lead compounds formed within the pipe.

Some alarmist statements have been made by Tweedy and Dudgeon* on the destruction that is taking place in the overhead equipment of tramways. Through the combined effects of chemical corrosion, local action, and direct electrolysis, a very short life is predicted for overhead work. I am unable to verify that these troubles are so bad as is represented. Of course, all exposed metal work in a town atmosphere is liable to decay, and constant inspection followed by renewals is necessary, especially in the parts of the town where chemical works are situated. Much may be done in the way of preservation by the use of protective coatings. Eternal vigilance is essential with all town metal work. As to the alleged electrolysis, if we take the leakage current across a span wire as $\frac{1}{1000}$th of an ampere, which may be considered a limiting estimate for Manchester, with its triple insulation, then the corrosion of iron or copper will be per month less than 1 gramme, which nevertheless should cause noticeable pitting. This supposes that the whole of the current passes from bare metal to an insulating surface covered with moisture, due to very frequent rain, and that the leakage is continuous. As a rule the leakage current will be about $\frac{1}{10000}$th of an ampere.

Electrolytic Surveys.

I am informed by Mr. A. Watts that about five years ago he undertook a series of tests for the National Telephone Company at Liverpool, Dundee, Sheffield, Leeds, Bradford, and Hull, but found no evidence of sufficient potential differences due to stray currents likely to cause electrolytic trouble.

The engineers of the Postal Telegraphs in London are experiencing trouble with small distribution cables, but they find that it can be guarded against by the use of petroleum jelly liberally supplied when drawing in lead-covered cables. Although the Board of Trade conditions have been fulfilled, when the cable sheaths have been cut and an ammeter inserted, readings as high as $\frac{1}{4}$ of an ampere have been noticed. Currents have also been found on the sheathing of cables on the routes of conduit system tramways with an insulated return. In a recent case, when a cable was damaged, a current of about 30 milliamperes was leaving the cable in the damaged section of the pipe. The local electric supply was alternating, and the nearest tramway (on the conduit system) was 2 miles distant. There were no works in the neighbourhood to account for the *direct* current which was measured. Stray currents are found circulating in the pipes and cables in every part of the Metropolis. The above particulars have been kindly furnished by Mr. E. Gomersall with the consent of Major O'Meara.

An official electrolytic survey of the Metropolis and some of the larger towns would be of great interest, and would help to decide the question whether any revision of the Board of Trade rules is desirable to prevent electrolytic trouble that may be due to the combined leakages of the electrical systems.

* *Journal of the Institution of Electrical Engineers*, vol. 37, p. 161, 1906.

XXII.—Electrical Endosmose.

An electrical current exerts a certain force on water whether in the ionic state or not. This action is made manifest in the case of moisture in porous materials and is included under the phenomena of *electrical endosmose*. It has been found that the mass of the water transferred is proportional to the coulombs that pass and is independent of the area and thickness of the porous substance. The endosmose effect is a common cause of faults in buried conductors, which are usually found at the negative main. On the negative side there is a constant strain on the insulation tending to drive water through the insulation to the copper.* When the water gets in, electrolysis of the alkaline salts that

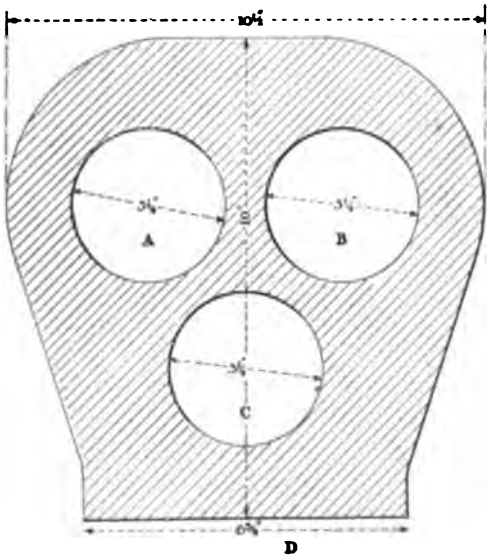


Fig. 13.

are in solution takes place, and alkalies or alkaline metals are produced. An interesting example is detailed by H. Bassett, jun.† A bad earth was caused on a negative main at Liverpool. The cable had been jointed at the faulty place and around it was found a hard substance that contained caustic soda, and potash, and a liquid alloy of potassium and sodium. The free metals in contact with water liberate hydrogen which, when mixed with air, forms an explosive mixture that may have caused some of the mysterious detonations that have taken place in mains. The endosmose trouble will be aggravated at high voltages and may prove an obstacle in high-pressure direct-current systems.‡

* F. Fernie, *Electrician*, vol. 57, p. 125, 1906.
† *Ibid.*, vol. 58, p. 1009, 1907.
‡ L. Andrews, *Journal of the Institution of Electrical Engineers*, vol. 38, p. 528, 1907.

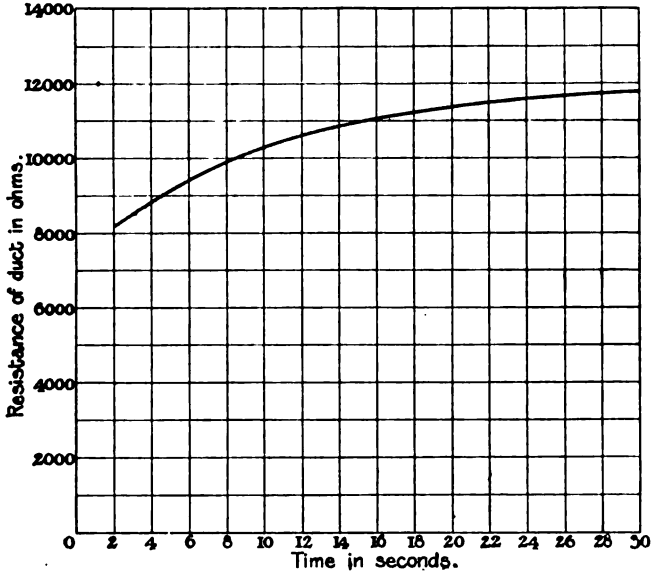

14000
12000
10000
8000
6000
4000
2000
Resistance of duct in ohms.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Time in seconds.

FIG. 14.

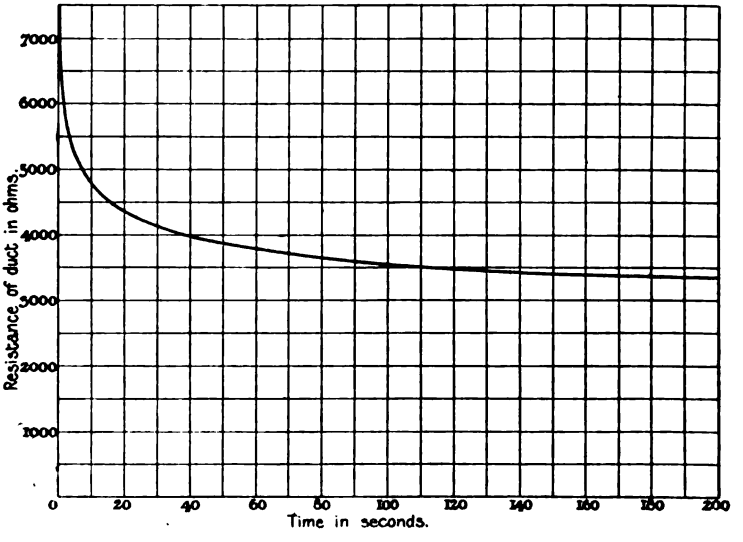

7000
6000
5000
4000
3000
2000
1000
Resistance of duct in ohms.
0 20 40 60 80 100 120 140 160 180 200
Time in seconds.

FIG. 15.

C. H. Wordingham has noted that certain makes of rubber are porous and water may enter and eventually destroy the whole of the rubber on the negative conductors.*

Not finding much experimental evidence on the effect of the conveyed water on the resistance of concrete, soils, and other porous materials, a number of observations have been made.

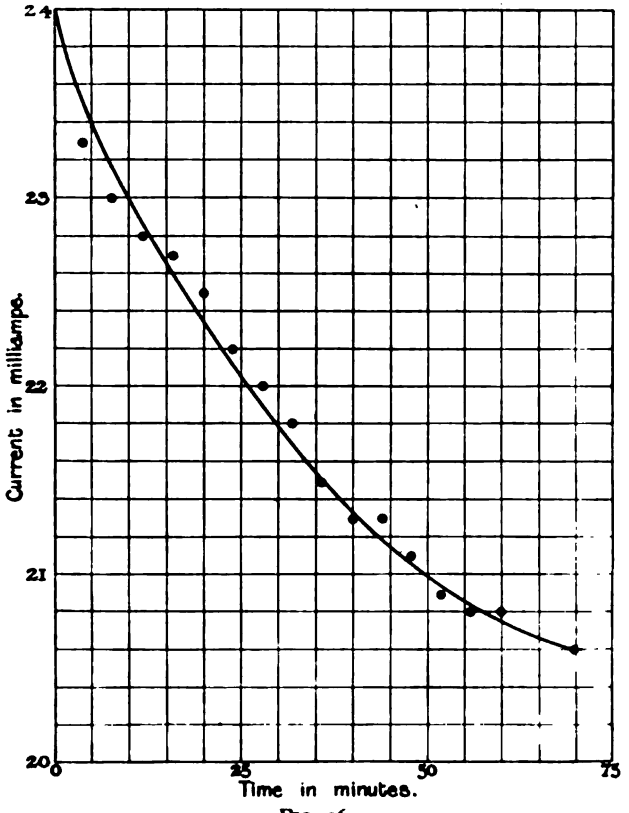


FIG. 16.

Experiments with Concrete Duct.—The 3-way duct used was kindly provided by the National Telephone Company. Its dimensions are shown in Fig. 13. It was placed in a tray containing mercury, and mercury was also placed in the ducts, being retained in place by walls of plaster of Paris. The resistance between C and D was measured by the alternating current method of Kohlrausch, a bridge arranged for the purpose by Hartmann and Braun being used. The mean resistance was found to be 3,550 ohms. A voltage of 110 was now applied, and readings of the current by a milliammeter were taken at intervals of

* *Electrical Engineer*, vol. 26, pp. 93–96, 1900.

time. The results are given in Table IV. and are plotted in Fig. 14 The polarity was some time afterwards reversed and readings given in Table V., which are plotted in Fig. 15, resulted. Next the resistance was measured between A and B. This was 6,600 ohms. On applying

TABLE IV.

Time.	Volts.	Current.	Resistance.
Seconds.		Milliamperes.	Ohms.
2	114	14·0	8,150
4	114	13·0	8,770
6	114	12·0	9,500
8	114	11·5	9,930
10	114	11·0	10,400
12	114	10·8	10,550
14	114	10·6	10,750
16	114	10·4	10,960
18	114	10·2	11,180
20	114	10·0	11,400
25	114	9·8	11,650
30	114	9·7	11,770
After 2½ hours	114	3·5	32,600

TABLE V.

Time.	Volts.	Current.	Resistance.
Seconds.		Milliamperes.	Ohms.
—	112	15·0	7,470
2	112	19·0	5,900
4	112	21·0	5,340
6	112	22·0	5,100
8	112	22·5	4,980
10	112	23·2	4,830
12	112	24·0	4,670
14	112	24·7	4,540
16	112	25·2	4,450
20	112	25·8	4,350
30	112	27·0	4,150
40	112	28·0	4,000
50	112	28·7	3,910
60	112	29·3	3,830
70	112	29·9	3,750
80	112	30·3	3,700
90	112	30·9	3,630
100	112	31·3	3,580
110	112	31·7	3,540
120	112	32·2	3,480
140	112	32·7	3,430
170	112	33·1	3,390
200	112	33·7	3,330

the direct voltage the figures in Table VI. and curve Fig. 16 resulted. In the above cases, the duct having been exposed to the air of the laboratory for some weeks, the concrete was fairly dry.

The duct was then soaked for two days in water and the resistance measured by the Kohlrausch method from time to time for about four weeks. Table VII. gives the result of the drying on increasing the resistance.

The length of the duct used in the experiments was 13 in., hence the resistance between the outside and inside a duct will, when in a wet condition, be less than 1 ohm for 100 yards.

TABLE VI.

Time.	Amperes × 10^{-2}.	Time.	Amperes × 10^{-2}.
Minutes.		Minutes.	
—	2·40	36	2·15
4	2·33	40	2·13
8	2·30	44	2·13
12	2·28	48	2·11
16	2·27	52	2·09
20	2·25	56	2·08
24	2·22	60	2·08
28	2·20	70	2·06
32	2·18	80	2·02

TABLE VII.

A Between Lower Channel and Bottom.
B Between Two Upper Channels.

Days.	A Ohms.	B Ohms.
0	250	785
2	335	1,010
4	430	1,300
5	474	1,390
6	516	1,500
27	2,350	8,060

Experiments with Concentric Electrodes.—The duct not being adapted for measurements on specific resistance, experiments were now made with regular shapes. Concrete was cast within a tinned iron cylinder provided with a central iron cylinder so as to give concentric electrodes. Successive measurements by the A.C. method gave 35 ohms. Then from the formula—

$$\rho = \frac{2\pi l R}{2{\cdot}303 \log \frac{r_2}{r_1}},$$

where $r_2 = 10{\cdot}2$ cms., $r_1 = 2$ cms., $l = 7{\cdot}4$ cms., the specific resistance is 3,840 ohms per cm. cube, or 41·9 ohms per yard cube.

A determination made in the same way, but with a mixture of equal parts of concrete and fine sand, gave 5,970 ohms per cm. cube = 65·5 ohms per yard cube.

Experiments with Concrete Blocks.—In order to test the influence of different electrodes on the change of resistance with time, a block was cast of equal parts of concrete and fine sand. It was a cube of 3-in. side. Two plates of carbon were used as electrodes, one being placed at the bottom and one at the top. As good a contact as possible was obtained by the pressure of a 56-lb. weight placed on the top. On applying 110 volts the resistance *increased in the same manner as in the previous cases.* The resistance measured by the A.C. method gave a very high value (1,164,000 ohms). Mercury electrodes were then substituted. The block was placed in a layer of mercury and an upper electrode also of mercury was used. This was held in place by cementing paper round the upper edges of the block. The resistance now was about 30,000 ohms. The experiment shows that the contact of the carbon with the cement was very imperfect. The specific resistance calculated from the last figure was 228,000 ohms per cm. cube, or 2,500 ohms per yard cube.

A block of the same size, but made of pure cement, gave—

Specific resistance, cm. cube = 158,000.
Specific resistance, yard cube = 1730.

It was thought desirable that in further experiments on concrete that the specifications of the Standards Committee should be followed in the making up of the test blocks. Cement and sand satisfying the required conditions was obtained and the blocks made up under the supervision of Mr. D. Macgilp, Chief of the Works Department of the School of Technology.*

Four bricks were made, each 9 × 2½ × 3½in. A_1 of standard cement alone, A_2 of 3 parts of cement and 1 part of sand. These were left in the mould for five days, and then soaked in water for three weeks.

B_1 of cement alone, B_2 of 3 of cement and 1 of sand (all by weight). These were left in the mould for six days and then soaked in water for two weeks.

After they had been drying for about fourteen days the resistance was very high. They were then soaked in water for about eighteen hours, and when partially dry their specific resistances were obtained by the A.C. method and with mercury electrodes. The results are given in Table VII.

By March 2nd the resistance in each case was very high—about 60,000 ohms/yard cube.

A large cube of about 10-in. side was also made of 1 part of cement

* Engineering Standards Committee. British Standard Specification for Portland Cement. No. 12 revised, June, 1907.

TABLE VIII.

	February 28th. Ohms/Yard Cube.	February 29th. Ohms/Yard Cube.
A_1	200·0 partially dry	277 drying in laboratory
A_2	504·0 damp	6,610 ,, ,,
B_1	70·2 ,,	172 ,, ,,
B_2	709·0 ,,	3,990 ,, ,,

by volume, and 5 parts by volume of an aggregate consisting of broken granite, granite dust, and standard sand. It was after a prolonged soaking in water and when it was still dark in colour, owing to the

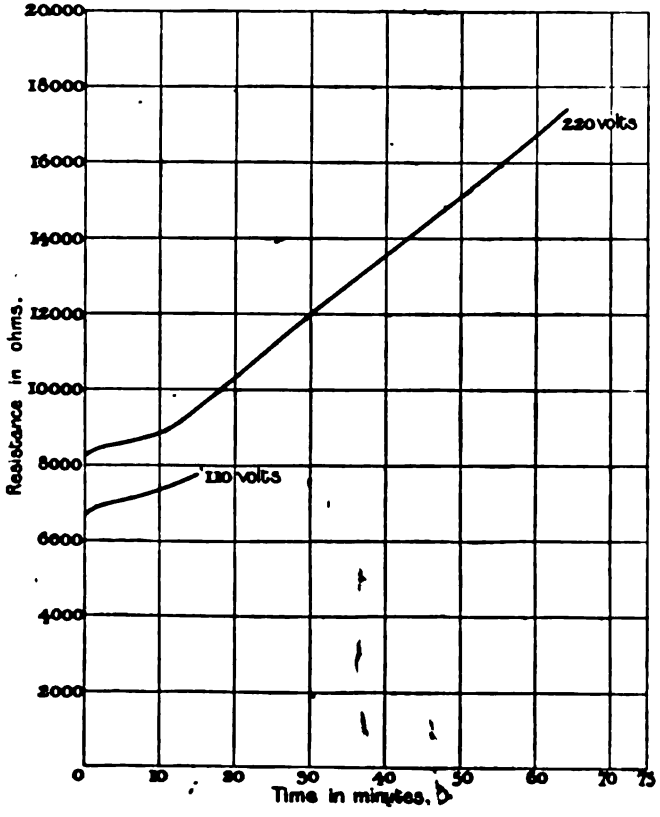
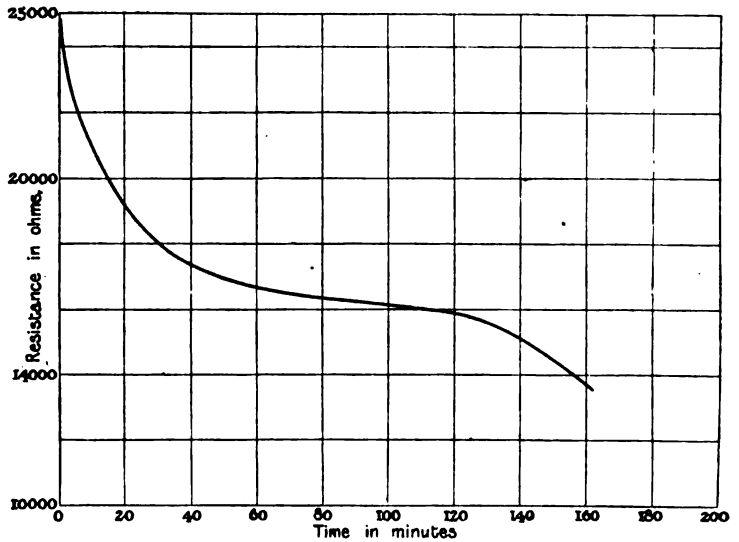


FIG. 17.

presence of water, the measurements were commenced. The specific resistances obtained were :—

	Ohms/Yard Cube
February 25th	57·5
„ 27th	102·0
„ „ (evening)	125·0
„ 29th „	392·0
March 2nd	2,000·0

Experiments with Sand.—Standard sand from Leighton Buzzard was placed in a glass trough and provided with soft-iron electrodes of



FIG, 18.

10·5 sq. cm.; when the sand was quite wet but without surface-water, and with the electrodes 5 cms. apart, the specific resistance was measured by the A.C. method and found to be 15,750 ohms per cm. cube.

A current from a 110-volt circuit was now passed through the sand and time observations taken as before. The calculated apparent resistances plotted against time is given in Fig. 17. The voltage was now increased to 220, when the upper curve of Fig. 17 was obtained. At the conclusion of the preceding experiments the current was reversed, when the change of resistance with time followed, Fig. 18. The polarisation was found to be small.

Experiments with Coke.—Roughly powdered coke with iron electrodes and moistened with Manchester rain-water. The resistance gradually decreased on applying a voltage of 10, probably due to the heating of

the carbon. The polarisation was 1·95, and the specific resistance about 20·6 ohms per inch cube.

Experiments with Aluminium Electrodes.—Pure aluminium-foil electrodes were used with damp sand moistened with a dilute solution of salt and gave with 25 volts a gradually increasing resistance as shown in Fig. 19. The anode corroded during the experiment. The current density at the end was about 0·0056 amperes per sq. cm.

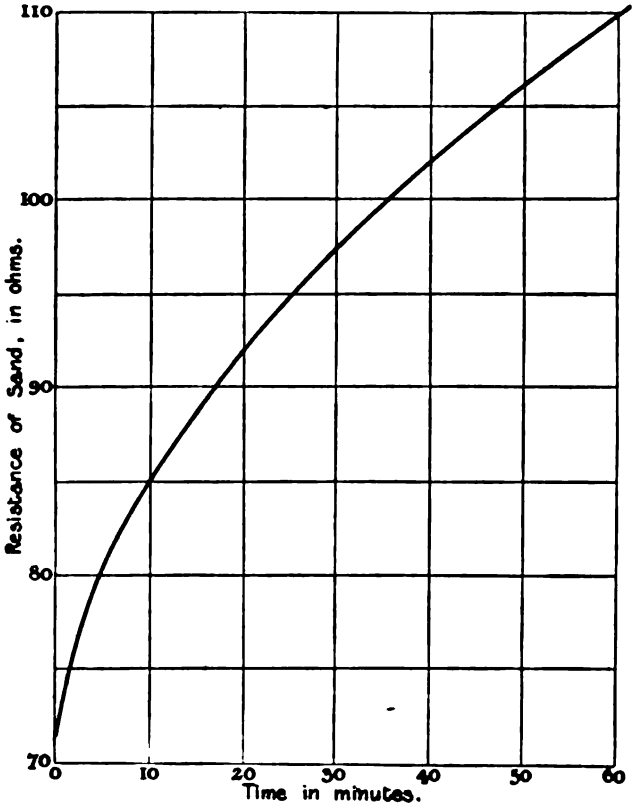


FIG. 19.

Experiments with Plaster of Paris.—A round rod, 18 in. long by 1 in. diameter, was made of ordinary plaster of Paris and water in a tube of sheet-lead used as a mould. When the plaster was well set the lead was cut through, so that the rod could be removed without breakage. It was fixed vertically and provided with mercury electrodes. A voltage of 110 was applied for 2 hours and 20 minutes, and then a voltage of 220 for 2 hours. The resistance, which at the start was 22,300 ohms, had now risen to 28,210 ohms. The rod was now broken

into three nearly equal pieces and the resistances of the two end pieces obtained. They were then weighed, and then heated for a long period until thoroughly dry. The results were :—

TABLE IX.

	Positive End.	Negative End.
Length	5·50 in.	5·75 in.
Resistance before drying ...	10,400 ohms	5,100 ohms
Resistance per inch before drying	1,890 ohms	887 ohms
Water lost on drying, in grammes per inch ...	5·77	6·80

A second series of observations was taken with a rod about 21 in. long and 1¼ in. in diameter. It was submitted to about 220 and then about 360 volts. The resistance change with time is given in Fig. 20. The current density averaged the whole time 0·00348 ampere per square inch, and during the experiment 0·0084 Board of Trade unit was used. At the conclusion the rod was broken up as before and the amount of moisture in each piece estimated, with the following results :

TABLE X.

No. of Piece from Positive End.	Resistance in Ohms per Inch Length.	Moisture per Inch Length. Grammes.
1	4,080	6·40
2	2,700	7·24
3	2,270	8·20
4	1,710	8·32

Discussion of the Endosmose Experiments.—It does not seem that the change of resistance that takes place is due to the effects of polarisation, or to a gradual building up of a non-conducting film at the electrodes. It was the same with mercury, carbon, and non-passive iron and aluminium electrodes. The values of the E.M.F. of polarisation obtained were low. There was plenty of evidence of the gradual drying of the positive electrode causing a change of the resistance around it.* The experiments with the plaster of Paris rods show the

* In later experiments the resistance at each electrode was measured. The resistance at the anode with 190–220 volts, after the temperature had become constant, increased in a very marked manner.

influence of the conveyed water on the resistance. The phenomena has some resemblance, as far as the rate of change of the resistance, to the observations of Trouton and Searle,* which relate to the change of resistance of surface films on glass.

Discussion of the Properties of Concrete.—The rapidly increasing use of concrete for structural purposes, etc., makes the study of its electrical properties of some importance. Its specific resistance according to the measurements that have been given in the case of pure cement vary from 20 ohms per yard cube when wet to 1,900 when fairly dry. The addition of sand does not make much difference when the concrete is wet, but its effect when very dry is greatly to increase the specific resistance.†

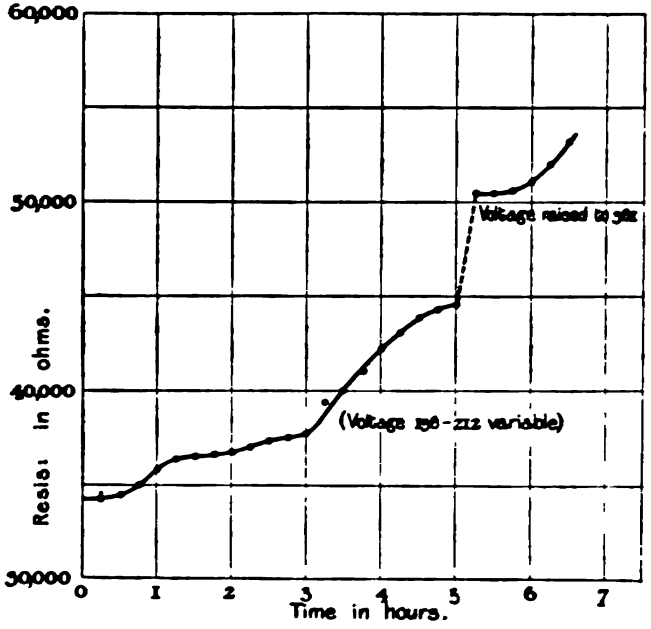


FIG. 20.

The specific resistance thus depends on the presence of water to a very important extent. The experiments on electrical endosmose show that water may be electrically conveyed and accumulate at cathodes.

The corrosion of structural steel embedded in concrete by the action of stray currents is a matter of concern in the United States. Toch has shown that steel embedded in concrete can be electrolytically corroded at the anode, but if a good insulating paint be applied to the

* *Phil. Mag.* vol. 12, p. 336, 1906.

† The limits obtained by St. Lindeck, *Elektrotechnische Zeitschrift*, vol. 17, p. 180, 1896, give for cement after 72 hours immersion in water 435 dm. cube, and one part of cement and seven parts of gravel after drying for 4½ hours at 100° C. 6,950,000 ohms/dm. cube.

steel corrosion can be prevented. Some drastic experiments showing the effect of relative large currents on iron in concrete have been described by A. A. Knudson.*

In the absence of vagabond currents, iron in properly made concrete is perfectly preserved without loss of weight, and even if used in a rusty state it will recover after some time the tint which it originally possessed. This almost incredible fact is thought to be due to the action of the cement in forming a protective coating of silicate of iron.†

Technical Applications of Electrical Endosmose.—Electrical engineers will be interested in the efforts that are being made to apply electrical endosmose for the drying of peat, the extraction of sap, and in the processes of tanning.‡

The method of drying peat is illustrated by the following experiments :—

1. An electrode of iron-wire gauze was fixed at the bottom of a large glass funnel, 10 in. in diameter, which was then filled up with 1,530 grammes of damp peat. On the top of the peat a heavy lead plate was placed and then connection was made to the 200-volt mains, the upper electrode being the anode. The change of current with time was like the case of the concrete. Water trickled out of the funnel, and in two hours 125 grammes were collected.

2. A shallow wooden tray, about 2 ft. long, 8 in. wide and 6 in. deep, was made and well varnished. The bottom consisted of a perforated zinc plate. The box was filled with wet peat and an upper electrode, the anode of iron pressed down with weights was used. With 500 volts the current fell in an hour from 3·3 to 0·7 amperes, and the bottom of the box was saturated with water.

XXIII.—Alternating-current Corrosion.

The Metropolitan Water Board having been successful in forcing the North Metropolitan Electric Supply Company to include in their 1907 Bill a clause by which the Company is liable for any electrolytic action from their alternating system has brought under debate the question whether or not alternating currents can produce corrosion.

The question is one of considerable scientific interest, and is settled as far as laboratory methods are concerned. Even with a periodicity as high as 600 per second copper can be rapidly corroded in a solution of potassium cyanide. This may be due to the great rapidity of the reaction between the copper liberated during half a period, and the cyanide leading to the formation of complex substances which cannot be decomposed by the reversed current. The periodicity of commer-

* *Proceedings of the American Institute of Electrical Engineers*, vol. 26, pp. 133–148, 1907.

† See E. Noaillon, "Ferro-concrete and Some of its Characteristic Properties," *Proceedings of the Institution of Mechanical Engineers*, p. 485, 1905.

‡ See Watt's "Leather Manufacture," pp. 254–259, for several processes. *Industries and Iron*, vol. 27, p. 83, 1899, for Groth's method. German patents 124,509, 124,510, 128,085. J. Buse, *Industrie Electrique*, vol. 8, pp. 344–348, 1899. von Schwerin-Höchst, *Zeitschrift für Elektrochemie*, vol. 9, p. 739, 1903.

cial alternating currents being more of the order of 50, the conditions for corrosion are more favourable, but, fortunately, the salts in the earth have not so far been found to give rise to complexes. On the other hand, it is found that the efficiency of corrosion is very small and that passivity may be produced and prevent corrosion altogether.

J. L. R. Hayden * has made a long series of experiments with lead and iron electrodes, using solutions of salts contained in the soil, and with the soils themselves, and he finds that the amount of corrosion rarely exceeds $\frac{1}{4}$ per cent. of the amount that would be produced by the equivalent direct current.

The result of some experiments made under my direction may be quoted here: Plates of commercial lead, copper, and soft iron about 5 in. × $1\frac{1}{2}$ in. × $\frac{1}{16}$ in. thick were immersed for 144 hours in either 1 per cent. or 7 per cent. solutions of sodium sulphate and the value of the chemical corrosion obtained. Pairs of plates, which had been each weighed, were placed in beakers containing one or other of the above solutions. The cells were arranged in series and an alternating current of 80 ∿ and 2·5 (R.M.S.) amperes was passed for $6\frac{1}{2}$ hours. The plates were then withdrawn, washed, dried, and re-weighed. The results are given below:—

TABLE XI.

Metal.	Solution.	Total Corrosion in $6\frac{1}{2}$ Hours.	Chemical Corrosion in $6\frac{1}{2}$ Hours.	Equivalent Direct-current Corrosion.	Percentage of A.C. Corrosion to D.C. Corrosion.
	Per Cent.	Grammes.	Grammes.	Grammes.	
Lead ...	7	0·038	0·002080	56·50	0·060
Lead ...	1	0·032	0·002030	56·50	0·053
Copper ...	7	0·030	0·000902	17·24	0·150
Iron ...	1	0·061	0·003740	10·70	0·500

In a second series of experiments a normal solution of sodium chloride was used, and the electrodes were of soft commercial lead and transformer iron. The area of each plate was 100 sq. cms. They were first allowed to corrode for 613 hours, and after being cleaned, dried, and weighed, were submitted in pairs of the same metals to alternating-current electrolysis with a virtual current of 1·5 amperes at 60 ∿, the voltage across each cell being 1·5. Gas was observed on all the plates, and in the case of iron a considerable amount of rust was produced whenever a bubble adhered to the surface. The alternating current hence seemed to promote rusting. The lead plates were

* *Proceedings of the American Institute of Electrical Engineers*, vol. 26, pp. 103–131, 1907; and *Electrician*, vol. 58, pp. 969–972, 1907.

dipped in very dilute acetic acid before cleaning and drying. The average results are shown below:—

TABLE XII.

	Hours.	Combined Corrosion.	Chemical Corrosion.	Current Corrosion.	Equivalent D.C. Corrosion.	A.C. Corrosion / D.C. Corrosion
		Grammes.	Grammes.	Grammes.		Per Cent.
Lead...	15	0·127	0·00510	0·122	81·9	0·015
Iron ...	15	0·075	0·00147	0·073	22·2	0·330

One aspect of the leakage of alternating currents is whether they are capable of rectification by the valve action of certain metals such as iron, lead, and copper. This requires investigation.

In conclusion I must express my thanks to my colleagues who have placed information at my disposal, and I must especially thank Messrs. Butterworth, Bleakley and Brotherton for assistance with experimental work. I am also indebted to several students, and wish to particularly mention Messrs. A. K. Bentley, G. H. Taylor, B. Hoyle, and D. Jenkins.

APPENDIX A.

CALCULATION OF CONDUCTANCE CAPACITY OF AN ELECTROLYTE DUE TO THE PRESENCE OF GALVANIC COUPLES OF SIMPLE GEOMETRIC FORM.

(By S. BUTTERWORTH, B.Sc., Manchester.)

It will be assumed that the conductance *of the electrodes* is always great compared with the conductance capacity K, and therefore that the bounding surface of each electrode with the electrolyte is an equipotential surface. The method adopted is to choose a certain system of equipotential surfaces, and to find the value of K for that system when our two electrodes have boundaries coinciding with any two surfaces of that system.

The simplest system to take is that in which the surfaces are represented on a plane by a system of circles all passing through one point O, and having their centres on a straight line Ox (Fig. 21).

In this case the current sheets will be represented by circles having their centres on the common tangent Oy, and all passing through O. The elementary area to take is one bounded by equipotential circles of radii x and $x + dx$, and by two lines of flow of radii y and $y + dy$. Such an element is A B C D in Fig. 21. The size of this element is—

$$\left.\begin{aligned} \text{A B} &= \frac{2x^2\,dy}{x^2+y^2} \\ \text{D A} &= \frac{2y^2\,dx}{x^2+y^2} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (1)$$

The distance p of A from Ox is—

$$\frac{2x^2y}{x^2+y^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

and the distance q from Oy is—

$$\frac{2y^2x}{x^2+y^2} \quad \ldots\ldots\ldots\ldots \quad (3)$$

The value of K for the following galvanic couples is easily deduced from the above system :—

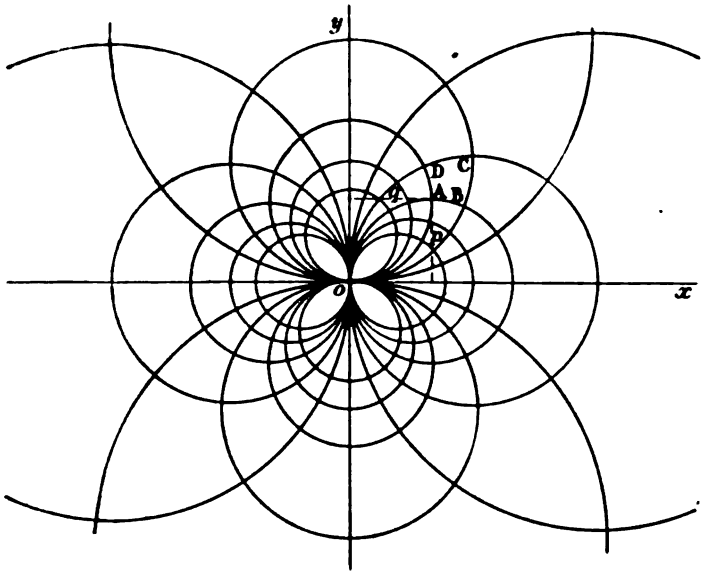


FIG. 21.

1. *Two parallel cylinders*, radii a and b, touching each other, and immersed in an electrolyte (Fig. 22).

It is obvious from the figure that if an electrolyte can penetrate right to O, the value of K would be infinite. Hence in order to obtain finite results, we must in this (as well as in the succeeding cases) assume a smallest line of flow within which the electrolyte does not penetrate. Let its radius be c_1 in the upper quadrants and c_2 in the lower quadrants. Again, if the electrolyte is of finite size, we must discover the greatest line of flow. Let the radius of this be d_1 in the upper and d_2 in the lower quadrants. Then for unit thickness of electrolyte and for the first quadrant the value of K (by reference to

Fig. 21) is seen to be $\Sigma \frac{A B}{D A}$ taken over whole quadrant. Therefore from (1)—

$$K = \int_{c_1}^{d_1} \frac{dy}{y^2} \Big/ \int_{b}^{\infty} \frac{dx}{x^2}$$

$$= b \left(\frac{1}{c_1} - \frac{1}{d_1} \right).$$

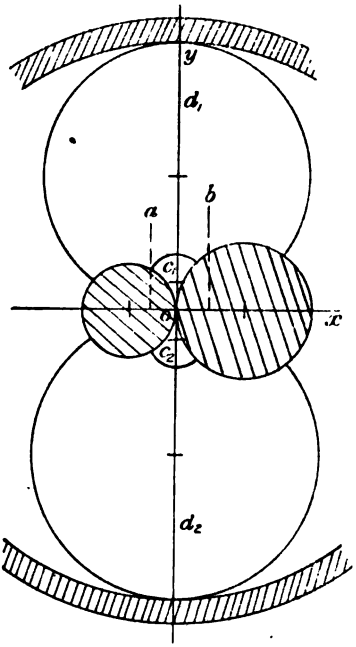


FIG. 22.—Section of two Cylinders immersed in Electrolyte.

For all the four quadrants and unit thickness—

$$K = \frac{a b}{a + b} \left(\frac{c_1 + c_2}{c_1 c_2} - \frac{d_1 + d_2}{d_1 d_2} \right).$$

Particular cases, such as cylinder on a plane, can easily be deduced from this general expression.

The value of K when one cylinder is *inside* the other (see Fig. 23) is—

$$\int_{c_1}^{\infty} \frac{dy}{y^2} \Big/ \int_{b}^{a} \frac{dx}{x^2} + \int_{c_2}^{\infty} \frac{dy}{y^2} \Big/ \int_{b}^{a} \frac{dx}{x^2} = \left(\frac{1}{c_1} + \frac{1}{c_2} \right) \frac{a b}{a - b}.$$

2. *Two spheres in contact.* Let their radii be a and b respectively. The system of surfaces is obtained by rotation of the system of Fig. 21 about Ox. Then—

$$K = \Sigma \frac{2\pi p}{D} \frac{A}{A} \frac{B}{-}$$

taken over the two upper quadrants. Therefore K_1 for the first quadrant—

$$= 2\pi \int_c^d \left[\frac{dy}{y^2} \Big/ \int_b^\infty \frac{dx}{x^2} \left(\frac{x^2 + y^2}{2 x^2 y} \right) \right]$$

$$= 2\pi b \left\{ \log_e \frac{d^2 (3 b^2 + c^2)}{c^2 (3 b^2 + d^2)} \right\}.$$

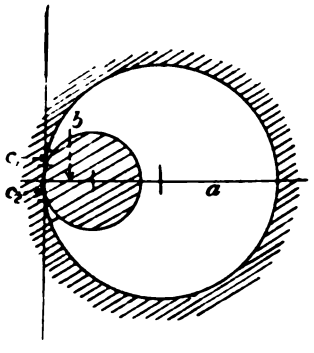


FIG. 23.

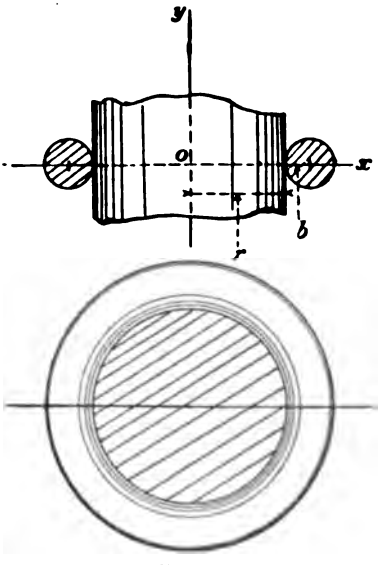


FIG. 24.

For the whole system—

$$K = \frac{K_1 K_2}{K_1 + K_2}$$

where K_1 = value for the first quadrant, and K_2 for the second quadrant.

K_2 is obtained by putting a for b in the expression for K_1. When c is large compared with b, K_1 reduces to—

$$6\pi b^3 \left(\frac{1}{c^2} - \frac{1}{d^2} \right).$$

3. *Ring round cylinder* (Fig. 24). Electrolyte of infinite extent. Let the radius of the cylinder be r, and that of section of ring be b. Then

the system is obtained from that of Fig. 21 by rotation of quadrants (1) and (4) round an axis parallel to Oy, and at a distance r to the left of it. Then—

$$K = \Sigma \frac{2\pi(q+r)\,A\,B}{D\,A}$$

taken over the right-hand quadrants.

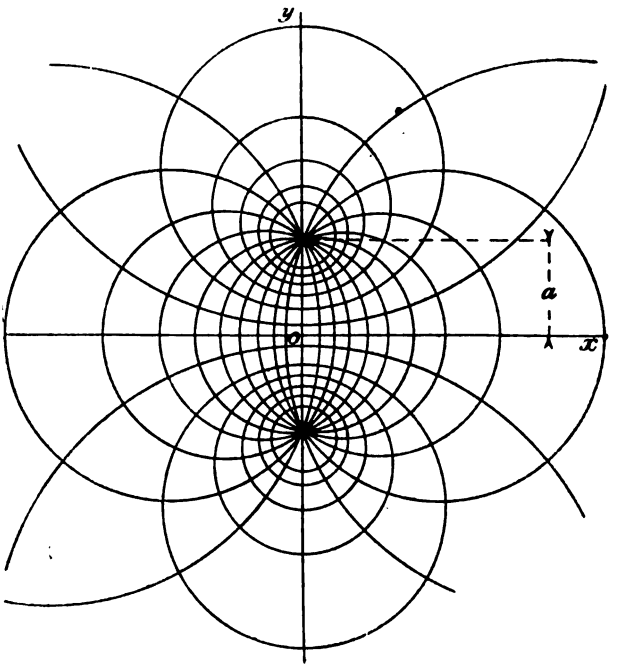


FIG. 25.

Therefore K_r for upper quadrant—

$$= \Sigma 2\pi \left(\frac{2y^2x}{x^2+y^2} + r\right) \frac{x^2\,dy}{y^2\,dx}$$

$$= 2\pi \Big/ \int_b^\infty \left[\frac{dx}{x^2} \Big/ \int_c^\infty \left\{\frac{dy}{y^2}\left(\frac{2y^2x}{x^2+y^2} + r\right)\right\}\right]$$

$$= 2\pi \Big/ \int_b^\infty \left[\frac{dx}{x^2} \Big/ 2\left(\tan^{-1}\frac{x}{c} + \frac{r}{2c}\right)\right].$$

If c be *small* compared with b, this reduces to—

$$2\pi \Big/\int_b^\infty \frac{dx}{2x^2\left(\frac{\pi}{2}+\frac{r}{2c}\right)} = \frac{2\pi b r}{c}$$

and for the complete system—

$$K = \frac{4\pi b r}{c}.$$

A second system of surfaces is represented in Fig. 25. The equipotential surfaces consist of circles passing through two points on Oy at a distance a above and below O, with their centres on Ox. The previous system is included in this, since it is the case $a = O$.

The lines of flow will be circles everywhere at right angles to the equipotential circles. Their centres will therefore be on Oy.

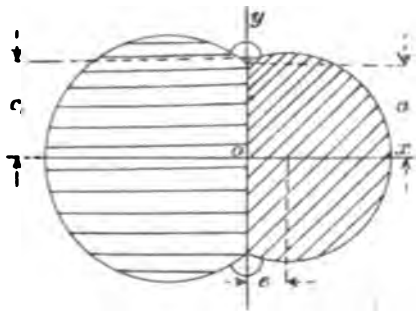


FIG. 26.

If $x =$ the distance of centre of one equipotential circle from origin, then the equation to this circle is—

$$r^2 - 2xr\cos\theta = a^2$$

and if $y =$ the distance of the centre of any one circle of flow from the origin, the equation to circle of flow is—

$$r^2 - 2yr\sin\theta = -a^2$$

where r and θ are the polar co-ordinates.

Working by methods similar to those of the first system, we get the following values for K for various couples, the electrolyte being assumed to be of infinite extent.

4. *Two uniform bars of metal*, whose sections are as in Fig. 26, K for the first quadrant and unit thickness, is—

$$\sqrt{\frac{c^2+a^2}{c_1^2-a^2}}$$

where c is distance from O of centre of circle which bounds the metal.

Similar expressions hold for the other quadrants. This includes case 1 when $a = 0$.

Since the expression only involves e^2 it is immaterial on which side of O the centre of the circle is.

When $e = 0$, then the expression becomes that for a hemicylinder.

For *two hemicylinders* of equal radius a placed with their flat surfaces in contact, K per unit length is—

$$\frac{a}{2}\left\{\frac{1}{\sqrt{c_1^2 - a^2}} + \frac{1}{\sqrt{c_2^2 - a^2}}\right\}$$

5. Solid produced by revolution of upper half of Fig. 26 about Ox. K for rotation of the *right* half—

$$= 2\pi\sqrt{e^2 + a^2}\left\{\frac{c^1}{\sqrt{c_1^2 - a^2}} - 1 + B\log_\epsilon \frac{\frac{c_1}{(c_1^2 - a^2)^{\frac{1}{2}}} - B}{1 - B}\right\}$$

where—

$$B = \frac{\sqrt{e^2 + a^2}}{2a}\left(\tan^{-1}\frac{a}{e} + \frac{a\,e}{e^2 + }\right)$$

This reduces to case 2 when $a = 0$.

A special case is that of *two hemispheres* ($e = 0$). Then—

$$K = 2\pi a\left\{\frac{c_1}{\sqrt{c_1^2 - a^2}} - 1 + \frac{\pi}{4}\log_\epsilon \frac{\frac{c_1}{(c_1^2 - a^2)^{\frac{1}{2}}} - \frac{\pi}{4}}{1 - \frac{\pi}{4}}\right\}.$$

APPENDIX B.

ELECTRODE PHENOMENA AT HIGH-CURRENT DENSITIES.

Some experiments illustrating what takes place when the anode or the cathode are submitted to electrolysis with a small area are given below :—

1. A copper wire was used as an anode in a normal solution of sodium chloride, the cathode being a copper plate enclosed in a porous pot. With a current density of 0·15 amperes per sq. cm. gas commenced to be evolved, and when the current density was increased to 4·48 a loud hissing sound was produced and the anode was rapidly disintegrated.

2. A piece of trolley wire No. oooo was bent in the form of a hook, so that the end could be seen on looking from above (Fig. 27). Indiarubber tubing was slipped over the wire to insulate all but the end. The electrolyte was as before, and the cathode was of copper

placed in a porous pot. With 114 volts a current density of 9·53 amperes per sq. cm. produced boiling round the electrode, and small sparks appeared at the edges. With 144 volts the current density increased to 10·6, and then a passive stage was reached. On raising the voltage to 150 the current density was only 0·42, but a bubble of gas escaped every half-minute and allowed rushes of current. A brilliant light was produced, which was still more marked at 233 volts. These experiments were made with a battery of storage cells without any external

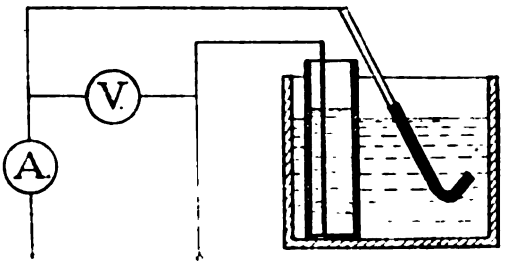


FIG. 27.

resistance, excepting that of the electrolytic cell. On changing over to the dynamo circuit a lower voltage of 200 gave a current density of 11·6. On changing back to the battery and inserting a choking coil a current density of 11·6 was obtained with 200 volts, when the amount

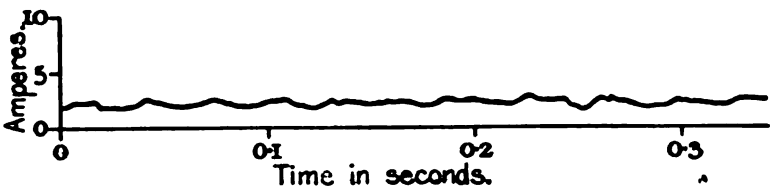


FIG. 28.

of self-induction was adjusted above a critical point. Continuing the experiments with the dynamo, 300 volts gave current density 27·5, 500 volts of 32·8, and 600 volts of 42·4. At these higher voltages the luminous effects were brilliant, and a loud sound was produced. At 600 volts the current was 40 amperes, so that the electrolytic cell was absorbing 32 H.P. As the containing vessel was only about 1 ft. in diameter and the same in depth, the experiment suggests an easy way of absorbing power, but it must be remembered that the current that is produced is a pulsating one. This is clearly shown by the oscillo-

grams (Figs. 28 and 29). Fig. 28 shows the effect of the battery alone, and Fig. 29 the result of introducing self-induction.

3. Using the same apparatus as before, but making the trolley wire negative, the following observations were made :—

TABLE XII.

Volts.	Current Density at Copper (Amps./Cm.^{2}).	Remarks.
1·25	0·026	Gas commences to be evolved.
9·60	0·740	Above action more vigorous. Cathode slowly blackens.
130·00	6·610	First appearance of yellow sparks.
150·00	6·350	Sparks whiter and the effect more vigorous. Loud noise.
300·00	14·800	Effects increased.
600·00	63·500	Brilliant light and loud rumbling noise. 36 k.w. = 48 H.P. absorbed.

4. The electrodes were now charged to arc-lamp carbons with the high-current density at the anode, a passive state was reached at 117

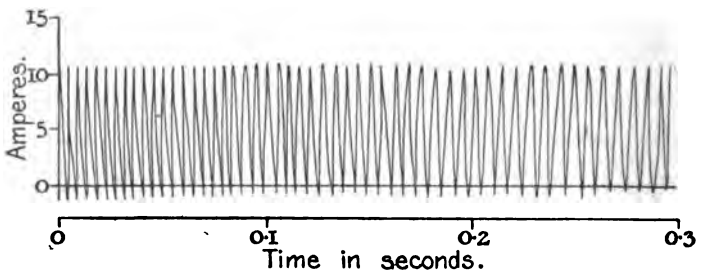


FIG. 29.

volts, when light appeared. From 150 to 500 volts from the dynamo there was a Wehnelt effect. At the last pressure the current was 30 amperes and the effect very brilliant and the noise violent. On increasing the voltage to 600 the current fell to about 1 ampere, and a slow boiling took place with the production of a yellow light. A second passive stage was thus produced. On reversing the current, the luminous effect resembled a flame arc, and 75 amperes at 400 volts was absorbed.

APPENDIX C.

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Also see the references given in the footnotes to this paper. For assistance in connection with this appendix I am indebted to Mr. G. H. Taylor, M.Sc.Tech.

Discussion.

Mr. A. Watts: With reference to electrolysis due to stray currents, the author of the paper has been good enough to mention my name with regard to some experiments I carried out some five to eight years ago in Liverpool, Dundee, Sheffield, Leeds, Bradford, and Hull. It will be remembered that about 1900, when electric traction was first seriously thought about in this country, there was somewhat of a scare as to what was going to happen to the pipes of the different gas departments, waterworks, etc., owing to reports which were circulating in America. The National Telephone Company, having a considerable interest in ducts and cables underground, determined to make some tests to see what was happening, and also whether the Board of Trade regulations were being carried out with a reasonable amount of care, and I took a series of tests on some of the first systems opened to find out what voltages we got at different parts of our cable system. Mr. Watts.

In the case of the Sheffield telephone system, the central exchange is near the centre of the town, and the main cables and ducts lead away from it and divide off at various convenient points, the lead-covered cable terminating at a pole on the house top or in the street. Now by joining up one of the spare circuits in the cable, a connection can easily be obtained from almost any point in the town to the test-room of the telephone system. Therefore in the test-room potential readings can be taken as desired. In the case of Sheffield, which was the worst, I found, after making a series of tests from different distributing poles, that at a particular point there occurred the lowest potential of the whole of the town, being even lower than that of the power station at Vulham Island. I made some inquiries from Mr. A. L. C. Fell, then tramway manager at Sheffield, and found that at this point the negative feeder had not been joined up. The tramway was only partly completed, and we got several peculiar results on certain of the uncompleted sections, but these are not of material interest. The most important test was from a point 3·6 miles from the centre of the town, where there was a drop on the cable of 1·5 volts, when practically the maximum tramway load was on. Readings were also taken between the rails and adjacent cables, and the highest readings on the outskirts of the town were about 1·25 volts with the rails positive to the cable, and in the centre of the town, within a small area of about a quarter of a mile square, there were readings varying from zero to 1·25 volts with the cable positive to the rail. Some details of an experiment made at Sheffield may be of some interest. Some half-dozen of the cables were bonded together at the point referred to where the lowest potential was found, and to give the current a slightly better chance of getting back to the rails, a copper earth plate 3 ft. by 2 ft. was sunk beneath the floor of a manhole. This plate has been in position since July, 1900, and when I heard of this paper I had the plate dug up. An examination of it shows a certain amount of pitting, but it is certainly not very alarming, especially when it is considered that the plate had

Mr. Watts. been used for draining a system of 20 to 30 miles of cable for a period of nearly eight years. The tests were all repeated when the tramway power station shut down to make quite sure that the readings obtained were due to the tramway currents.

We have been told that there is practically no stray current in the United Kingdom, and that we must go abroad for examples, but I came across one case some years ago, on the South Staffordshire tramways system, which was brought into use before the Board of Trade issued their regulations. This system includes Darlaston and Wednesbury at one end and Walsall about the centre, where we have an exchange. Between the power station and Darlaston there was a drop of 13·4 volts, and from the power-station to the far end of Walsall there was a drop of 16·7 volts. The Company has only a small system under ground in Walsall, and there being no differences of potential on that particular cable system of more than 3 volts, nothing was done in the matter.

There are two questions I should like to ask:

1. The author mentions that the Post-office engineers have obtained some readings of quarter of an ampere by cutting a lead-covered cable. I would like some further particulars as to how the test was made and the instruments used, and the conditions.

2. With reference to the concrete tests, it struck me that some of the tests made in this case were not quite commercial tests. They were apparently made with standard sand or granite of various kinds, presumably quite clean and free from clay, etc. In ordinary work one does not always use such good material, and it might be interesting to compare some commercial concrete with the standard material.

Mr. Cunliffe. Mr. J. G. CUNLIFFE: Like the last speaker, I propose to refer to the question of corrosion due to stray currents. Parshall in England and Claude in France have shown that, although comparatively large currents flow in the earth, yet only very small currents (in the neighbourhood of 1 ampere) are to be found flowing in the pipes alongside the track. I have endeavoured to find the reason for this, and although my experiments are by no means complete, I have succeeded in evolving a theory which, I venture to suggest, is at least plausible.

Fig. O shows the results of experiments which I have carried out with a view to determining the factors affecting the electrical resistance between two metallic bodies buried in the earth.

Curve A represents the variation of resistance between two metallic points.

Curve B, the resistance between a point and a plate; and curve C, the resistance between two plates.

Although I have given the scale of abscissæ, I have not shown the specific values of the resistance. This is because the resistance depends so largely upon the area of the plates and the specific resistance of the soil, which is itself a very variable quantity. I wish, however, to draw attention to the general shape of the curves, which appears to be the

same under all conditions within the range of my experiments. It will be observed that at small distances the resistance is high, whilst at larger distances it is relatively small. Mr. Cunliffe.

Fig. P shows the stream lines of current flowing between earth plates placed close together. Evidently the length of the extended stream lines is disproportionately great, so that the effective area of the path is not much greater than the area of the plates themselves. This is easily proved by comparison with the specific resistance of the soil.

Fig. Q shows the stream lines with the earth plates far apart. Evidently the percentage increase in length of the extended stream

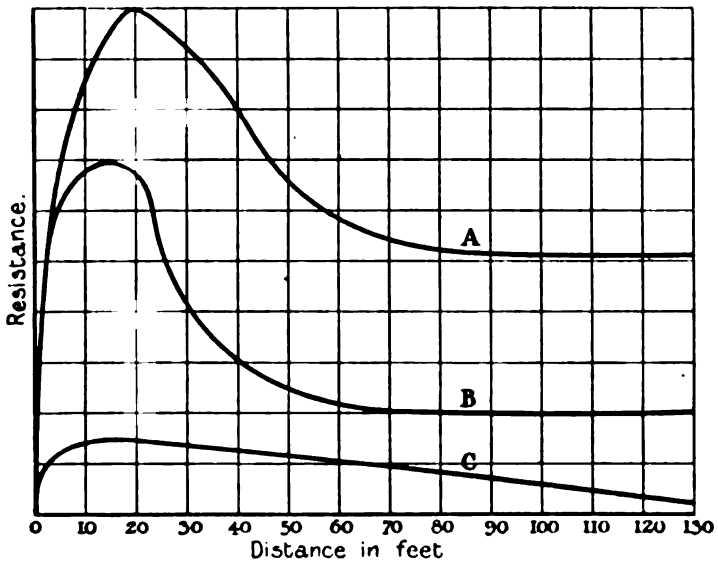


FIG. O.

lines is not so great, and the effective area of the path is enormous compared with the area of the plates. Hence the shape of the curves.

Fig. R shows the standard vagabond current diagram. Current leaves the rails at the point Y, and enters again at the distant point X. By the above reasoning, it is obvious that the resistance between the rail and the pipe which is laid beneath the surface of the same roadway is high, whilst the resistance to flow through the earth direct from Y to X is small. Thus the majority of the leakage current flows in the earth itself, only a very small percentage flowing in the pipe. Again, the same reasoning shows that between adjacent lengths of a pipe system the resistance to shunting of the current round the

Mr. Cunliffe.

joint must be high, and I have myself found this to be as high as 30 ohms with only $\frac{1}{8}$ inch space between the pipes. Thus, even if there is a current flowing in a pipe, the resistance of the joint must be very high in order to compel that current to take the earth path.

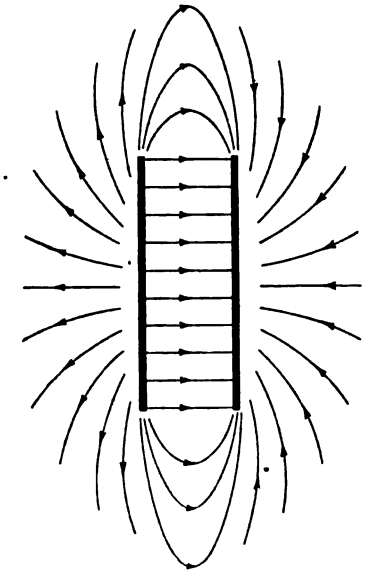


FIG. P.

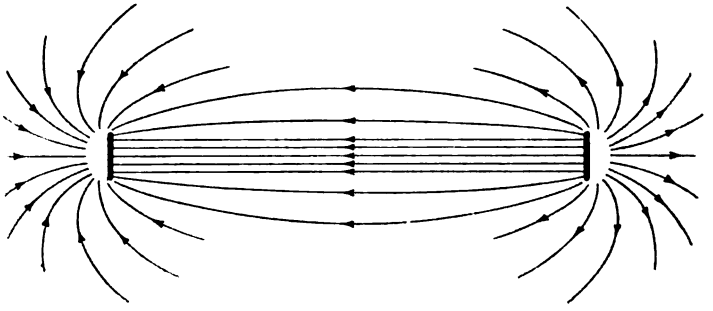


FIG. Q.

With regard to electrolytic surveys, I claim that no definite information can be obtained from them. As a matter of fact, the potential difference between a pipe and the rail at any point is greater the smaller the leakage current flowing in the pipe; so that, if the latter is zero, the potential difference is equal to the potential difference between

that point on the rail and the point where the rail is at the potential of normal earth, that is, the potential difference between the pipe and the rail has the maximum possible value under conditions of maximum safety, whereas generally this high potential difference is accepted as a sure sign of danger. In fact, careful consideration shows that electrolytic surveys are so apt to cause wrong impressions that they certainly ought never to be published. Mr. Cunliffe.

I shall now pass to the overhead line. Taking the case of an ordinary insulator bolt; under the influence of capillary attraction, and, to a far greater extent, of electrical endosmose, water charged with atmospheric impurities is drawn between the iron bolt and the insulating material, and is forced through from the positive metal of the bolt to the negative metal of the hanger.

This impure water is, as Professor Gee has shown, and as we of the Manchester Tramways are only too well aware, a very powerful electrolyte. Electrolytic corrosion immediately sets in, and rust is

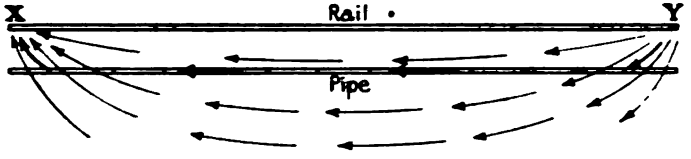


FIG. R.

formed in the practically capillary spaces, with the inevitable result that, as the rust film increases in thickness, the insulation is burst asunder.

This applies to almost every form of traction line insulator, and and can be remedied by inversion of the insulator bolt, or by reversal of the polarity of the line. The reversal of polarity also has the effect of reducing the current density where leakage currents leave an underground pipe, as is shown by every possible method of calculation or computation of leakage current density, and since there is far more chance of the pipe metal becoming automatically passive at low current densities, I think the suggestion is worthy of consideration.

In conclusion, I may say that, judging by the high E.M.F.'s of polarisation, after shutting down, the pipes in the Manchester streets are in a fairly passive condition, and so immune from attack by stray currents.

Professor A. SCHWARTZ: This subject of electrical corrosion is one which deserves a great deal more attention than we have paid it. I hold, for instance, in my hand a sample of an earthing clip; the design is ingenious and effective. Regarded from the point of view of electrical corrosion, one can only say it is a concentrated sin. We have tinned copper in contact with lead in contact with zinc which is on iron, which is again in contact with brass. With regard to the life of steel embedded Professor Schwartz.

Professor Schwartz.

in concrete, I think corrosion is rather an important point, because steel is entering so very largely into our structural work nowadays. As electrical engineers we have to deal with it not only in buildings, but it is used very frequently as ferro-concrete in the construction of flumes in hydro-electric work, and also in the construction of masts for long-span transmission lines. I have some results of experiments I made some time ago on steel embedded in coke breeze concrete, and I find in each case that, after exposure to steam and air and water with the various strengths of cement and sand and coke breeze which are usually employed, in every case severe corrosion followed. But if the steel were coated with neat cement, then it seemed to exert a considerable protective influence upon it, and I think in the early days of steel ships it was not an uncommon practice to coat the interior with cement. There is one point with regard to rusting I should like to ask the author. The presence of carbon dioxide seems to be necessary, and we know that iron and steel have the power of occluding a considerable amount of gas. They can occlude as much as ten or twelve times their volume of gas. On heating such a piece of iron or steel, we find that carbon dioxide is given off at the lower temperatures, and I should like to ask the author whether, in his opinion, he thinks that the CO_2 thus given off on heating—even if the surface of the material were protected by paint or some other protective medium—would be sufficient to cause corrosion.

I wish the author could have given us a little more information about endosmose, as it is a very important point to electrical engineers. Some fourteen years ago, in connection with the St. Pancras system in London, we had a series of very bad explosions in the mains, due to the formation of metallic sodium and potassium by endosmose. The mains were bare copper laid in brick and concrete culverts, and there these blocks of salts split when they got heated by the earth current passing through them, and when the little metallic globules of sodium and potassium were exposed, a drop of water falling upon them from condensation on the manhole cover set fire to them. Professor Gee attributes the explosion to the hydrogen which is liberated by the electrolysis, but I think we have to lay the explosion at the doors of our friends the gas people. Any hole dug in the street of any large town is always soon filled with gas, and when the proper proportion for explosion is reached, it is liable to be fired by the sodium and potassium.

Dr. Garrard.

Dr. C. C. GARRARD: I would venture to criticise somewhat the method adopted by Professor Gee in the very interesting investigations he has carried out. The method used is based on the measurement of the current density. The true criterion in all electrolytic reactions is not the current density at the electrode, but the potential difference there. Looked at in this light, many curious electrolytic reactions become quite easy to explain. For example, anodic efficiency. If copper be going, for example, into solution, in a solution of copper sulphate, if the potential difference at the anode be kept low enough, the

action will be quantitative. If, however, the voltage between the anode and the solution be raised high enough, the anions of water, namely, O and OH, will be liberated, forming oxygen with corresponding lowering of anodic efficiency. Dr. Garrard.

The point I wish to emphasise is that the proper way to investigate all electrolytic problems is by measurement and examination of the voltage and not of the current densities.

Professor Gee mentions the fact that zinc dissolves in an acid with a velocity proportional to the electrolytic conductivity of the acid. This directly follows from the law of Gouldberg and Waage and the laws of electrolytic conduction. Gouldberg and Waage's law tells us that the reaction velocity of any chemical reaction is a function of the concentrations of the reacting and formed bodies. As also the electrolytic conductivity is, within wide limits, proportional to the concentration of the acid, it will be seen that the relation found by Professor Gee is to be expected as a direct result of known laws, and does not need the formulation of any new hypothesis to explain it.

As regards the cleaning of iron articles by means of cathodic action, I worked out a process for doing this some years ago with the object of removing the rolling scale from rolled steel sections. The steel was used for steam turbine blades, and the rolling process covered it with a hard blue scale, which had to be removed before the machining was done. I used dilute sulphuric acid with carbon anodes; the process worked very well, the sections coming out of the bath beautifully clean and bright.

Mr. W. CRAMP: There is one question I should like to ask with respect to the action that takes place on tram rails. In the city here (I have noticed it also in other towns where trams are run) there may be seen on the rails—due, as I think, to the constant sparking and rolling occurring under the car wheels—a very beautiful, hard coating, apparently of black oxide of iron. This coating is, I think, the very thing that has been sought for so long by gunmakers and others to protect the surfaces of rifles, etc. In the Birmingham Royal Small Arms Factory the process used for putting an oxide coating on is kept absolutely secret, and even then the result is poor compared to that I refer to. I wish to ask Professor Gee if it is not possible to make use of the effect produced by the tram wheels to design a process for putting a coating upon other articles for general commercial purposes. Mr. Cramp.

Mr. R. PORTER: I think the author is somewhat optimistic when he tells us we have to go to America to search for electrolytic troubles due to stray currents. I have, however, in England, in only the last few weeks, come across three separate places where trouble from networks of trams is beginning to show. In two of these cases the damaged cables are the property of municipalities supplying only alternating current, which made it all the more aggravating to the borough engineers concerned. Mr. Porter.

The higher the current density, the greater the effect of electrolysis. This has a most important bearing on cable systems. Con-

Mr. Porter. sidering the solid system, here we have the lead well insulated except at the bridges. Water is apt to creep between the bridges and the bitumen, with the result that here and there the insulation at these points breaks down, and if there are stray currents, owing to the insulation of the rest of the system, we get high current densities at these points and aggravated troubles. For this reason, solid systems must be frequently and carefully earthed. The same, of course, applies to a conduit system in which one cannot rely on the joints being watertight. An engineer told me the other day that the first time he employed metal bridges he experienced great trouble, the reason being that he had neglected to provide other earths, as he had considered the metal bridges good enough. Of course, the earthing provided by the bridges being very poor, he had to put matters right by carefully earthing as usual.

Dr. Rosenberg. Dr. E. ROSENBERG: I was very glad to find in the paper actual figures as to the electrolytic action of alternating current. Once I had occasion to see the effect of electrolytic corrosion in the bearing of a 3-phase slip-ring crane motor with a 2-phase armature, the neutral point of which was connected to the shaft. When in the metallic starter by a chance a point of the resistance was earthed, the current flowing through the body of the crane and through the bearing to the shaft wore out shaft and bearing rather quickly. I was surprised that the lubricating oil did not insulate, but found that some qualities of oil on the market have so much acid that electrolysis takes place in a rather unexpected degree.

I see that Professor Gee accepts the theory that the insulating action of an aluminium cell (passivity) is due to a film of aluminium oxide; I have heard also of the theory that the effect is not due to the metal oxide but to the accumulation of oxygen gas.

With regard to stray currents, the rules of the German Institution of Electrical Engineers mentioned in Professor Gee's paper were not accepted by the Society of Gas and Water Experts, and both Societies have now formed a committee to investigate the matter by experiments and researches before new rules are issued.

Professor Gee. Professor GEE (*in reply*): With respect to Mr. Watts' remarks about commercial concrete, I started with commercial concrete, and I obtained such inconsistent results that I thought it would be wiser to use standard materials. The subject in course of investigation is really the resistances of porous materials, especially in connection with electrical endosmose. One point which gives difficulty is the surface drying. This may be very rapid, causing the resistance of the whole block to appear to be extremely high, whereas the inside is wet and of low resistance. I think Mr. Cunliffe has hit upon a very profitable line of work in finding the conductance effects in the earth, and I am hoping that the methods of Mr. Butterworth may help him to be able to solve some of these problems.

I was interested in seeing Professor Schwartz's sample of alloy. I believe it is chiefly an alloy of potassium and sodium that is produced

Professor Gee.

by the direct electrolysis of the salts in the soil. Dr. Marchant has pointed out that the leakage from gas mains is probably the cause of many explosions in mains. I should like to consider further about the rusting of iron due to the occluded carbon-dioxide. We must remember that the carbon-dioxide is probably in a dry condition. We must have it with moisture to form an electrolyte.

With regard to terminal voltage I am well aware of the importance of this quantity, but *current density apart* plays an important *rôle* in many phenomena, as is especially evident when the electro-deposition of metals is considered. Reaction velocities can, of course, be deduced from mass actions, but we must not assume too hastily that all the actions are electrolytic. There is a school of physical chemists in America who have shown that the rate of solution of metals does not depend on the conductivity in the case of certain solutions (see the references given in the paper in connection with Section XVI.). The oxide film that Mr. Cramp has noticed seems to be well worthy of investigation, and the action of electric heating and pressure in producing oxides may be important. Mr. Porter said that we were perhaps too optimistic about corrosion in this country. Certainly the rapidly increasing use of electricity in lighting and traction systems in which both direct and alternating currents are used may give us trouble in the immediate future. I therefore have recommended in my paper that it would be desirable to know something about the conditions in the Metropolis. It may be necessary to make some modifications in the Board of Trade Regulations. With reference to alternating currents, it is quite possible, and first experiments show that it is more than possible, that alternating current may get rectified in the earth. About the cause of passivity, I have read numerous researches on the subject. Leblanc attributes it to a small speed of ionisation velocity, but its cause still remains obscure.

HEATING OF VENTILATED AND ENCLOSED MOTORS.

By WILSON HARTNELL, Member.

(*Paper received from the* LEEDS LOCAL SECTION, *March* 4, *and read at Leeds on April* 9, 1908.)

The evolution of the continuous current electric motor during the last fifteen years has resulted in a gradual decrease in size for any given output, without loss of efficiency. The smooth ring wound armatures have been replaced by slotted drum wound. The clearance between the pole-face and the armature is now comparatively very small, and the armature notches are wide, necessitating laminated pole-faces. The length of the armature is shorter in proportion to its diameter.

In consequence of these changes the magnetic flux in the air-gap has been raised from, say, 4,000 lines per square centimetre to 10,000 or 12,000. At the same time the ampere-turns on the magnets have been decreased and the magnetic leakage reduced to say $\frac{1}{4}$ to $\frac{1}{5}$ of that of the old ring-wound motors. The carbon brushes now run sparklessly in, or nearly in, the middle position, unaffected by reactance-voltage or by large field distortion.

The modern 4-pole motor is at a disadvantage, compared with the old 2-pole motors with copper brushes, in respect of dissipating the heat produced in working.

The heat produced in the armature and shunt winding is no greater than of old. The heat produced by losses in the teeth and armature discs is serious, with a dense magnetic flux in the air-gap; and can only be kept within reasonable bounds by a moderate surface speed of armature.

The heat due to the carbon brushes is considerable with low voltages. With a surface speed of 1,500 ft. per minute the loss due to friction, and the loss in volts between the carbon and copper, may easily be equal to from $1\frac{1}{2}$ to $1\frac{3}{4}$ watts per ampere per brush.

The heat thus produced can only be dissipated as follows:—

1. By heating the motor itself.
2. By radiation.
3. By conduction to a flow of cool air, that is, by ventilation.

It is impossible to separate these cooling effects by ordinary observation, but some assistance may be given by the following table,

which shows for a series of motors an assumed average weight, cooling surface and loss of watts. These data are founded on an actual set of standard motors.

There are also tabulated the square inches of cooling surface per watt; the time the motor would require for a rise of 72° F. (40° C.) in temperature, assuming that no heat escaped elsewhere; the cubic feet of cool air per minute that would be required to prevent the rise of temperature exceeding 72° F., also assuming that the escaping air were heated 36° F., and that no heat escaped elsewhere.

TABLE I.

Size of Motor, H.P.	Assumed Loss in Watts at Full Load.	Area of Enclosed Motor in Square Inches.	Cooling Surface per Watt lost.	Cubic Feet of Air per Minute the Watts lost could raise 30° F.	Weight of Motor.	Minutes in which the lost Watt could Heat the whole Motor 72° F.
3	380	1,000	2·6	31	300	113
5	580	1,300	2·2	47	470	100
7½	770	1,000	2·1	63	550	102
10	960	1,850	1·9	79	660	98
15	1,200	2,300	1·8	102	1,000	118
20	1,460	2,650	1·7	120	1,300	128
30	1,900	3,250	1·6	157	1,900	144
40	2,380	3,850	1·5	196	2,500	150
50	2,980	4,300	1·4	244	3,100	140
60	3,570	4,700	1·3	292	—	—
75	4,400	5,100	1·2	360	—	—
100	5,700	5,700	1·0	470	—	—

The relative change of these values, as the size of the motor increases, may be seen from Fig. 1.

From this it may be inferred that the heating of the motor itself is of practical value, when a motor works intermittently, as in a crane or a hoist, say, not running more than 20 minutes per hour fully loaded.

Radiation.—It will be seen that the cooling surface per watt of motor under 5 H.P. is nearly double that of motors over 50 H.P. The difference in the effectiveness of the cooling surface is far greater. For the hotter air inside the larger enclosed motor is near the top, the bottom of the motor remaining markedly cooler and therefore the radiating surface less active. Also the magnet case may be three or four times as thick in the larger motor, rendering the escape of heat from the metal proportionately less.

Thus, although 2·5 to 2·0 sq. in. of radiating surface per watt lost may suffice for small enclosed motors considerably more would be necessary to keep, say, a 50-H.P. enclosed motor equally cool.

In order that radiating surfaces be most efficient they must be opposite to cool surfaces, as all surfaces radiate heat in all directions. If there be a steam or gas engine or wall of a boiler-house near the

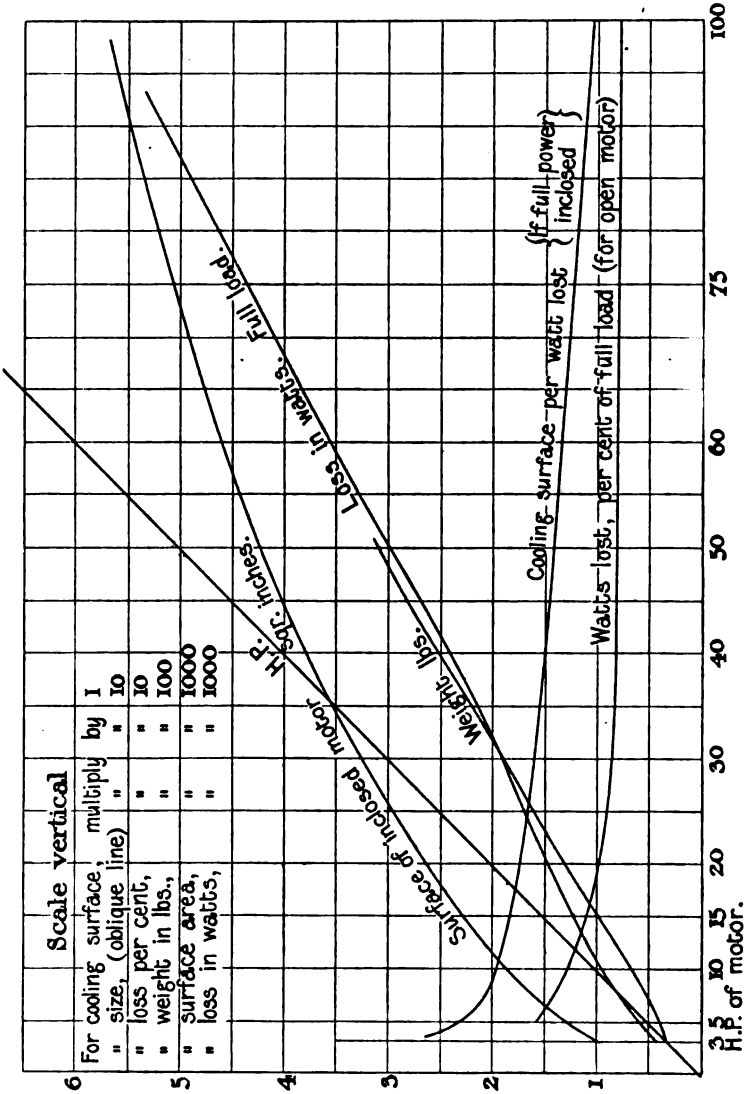


FIG. 1.—Averaged Particulars of a Set of Motors.

motor the effective radiation on that side of the motor will be partly neutralised although the intermediate air may be cool.

When an enclosed motor is required of more than, say, 3 H.P., the

usual means of obtaining the requisite cooling surface is to take a motor of larger size and reduce the output, the armature current being reduced—and therefore the armature reaction—and also the flux density in the air space and ampere turns in the poles. This reduces the heat due to losses in the copper and still more the heat due to core losses. By such means the total heat losses are reduced until the cooling surface per watt of the larger motor is sufficient for the diminished outputs.

This, however, makes a costly motor for continuous working, even for moderate powers; a 20-H.P. motor wholly enclosed may give 10 H.P. at a passable temperature, but a 30-H.P. motor would scarcely give 15 H.P. for the same temperature rise.

A more economical arrangement for an enclosed motor is to place an open motor that may be fully loaded under a thin sheet-iron cover with ample inspection doors. This has been found convenient and satisfactory in flour mills, the case, though merely resting on the floor, being practically dust-proof and inexpensive. The cover must be roomy because the heated air remains in the upper part of the cover, the lower part remaining cool, and therefore ineffective as a heat radiator.

Examples of open motors working satisfactorily fully loaded, placed in large covered recesses below the ground floor, and also enclosed in what might be compared to large, roomy wooden cupboards, are to be found in our clothing factories, many of which are driven by electric motors throughout.

Ventilation.—The cubic feet of air required to keep the temperature rise below 72° is probably not less than the quantity tabulated, viz., about 9 cub. ft. per horse-power per minute for the smaller motors under 10 H.P., and about 5 cub. ft. per horse-power per minute for motors over 30 H.P. Experience shows that large open motors working to their full load can, by the aid of ventilation and radiation, be kept within the limits of 72°. But when wholly enclosed they can only be kept cool by forced draught. From rough estimation it seems that at least double the quantity of air per minute is then required.

Electric motors, viewed in regard to their means of cooling, may be divided into eight classes.

1. Entirely open, having their bearings usually on a bed plate which carries the magnets. Suitable for large motors, say, over 100 H.P.

2. Protected open, the bearings carried by open covers at each end of the magnet case. This is the ordinary modern motor, say, from 100 H.P. to 2 H.P.

3. Enclosed ventilated. The same as No. 2, but with the openings covered by wire net or perforated metal. These are used in factories where the open motor is assumed to be less safe. If the mesh be not less than 4 per inch the ventilation is not much interfered with, but if the mesh be much less not only is the ventilation much impeded, but the wire-work is apt to become choked with dust and fluff, and the safety of the motor endangered.

4. Same as No. 2 or No. 3, but with a forced ventilation by means of a fan on the armature and a diaphragm or its equivalent to divide the fan suction from the delivery. This is necessary in an exceptionally warm place.

5. Totally enclosed. These are required for special purposes, and usually necessitate a considerable reduction in the output.

6. Covered motors. The same as No. 2 fully loaded, but covered by a roomy thin sheet-iron case, practically dust-proof, with openings for oiling and inspecting the brushes, the pulley standing outside the case.

TABLE II.

STANDARD.		AS TESTED.					RISE OF TEMPERATURE DEG. FAHR.				
Horse-power.	Revolutions.	Horse-power.	Revolutions.	O = Open. E = Enclosed.	Volts.	Hours on Continuous Test.	Air.	Field Coils.	Armature.	Commutator.	
3	1,250	3·00	1,080	O	220	6	68	24	25	20	
3	1,250	2·25	800	E	220	6	65	45	47	48	
3	1,250	2·20	780	E	220	10	64	56	75	71	
5	1,100	5·00	800	O	220	6	70	53	56	46	Mean test of 4 motors.
—	—	5·00	842	O	220	9	63	49	47	37	
10	900	10·40	925	O	220	5½	55	58	54	51	
—	—	10·40	853	O	220	9¾	67	43	53	55	
—	—	5·00	760	E	120	6	70	59	56	51	Mean test of 3 motors.
20	800	20·00	800	O	220	9½	63	49	47	25	
—	—	10·50	695	E	120	6	71	86	74		Mean test of 2 motors.
40	750	28·00	361	O	105	4½	70	65	70	80	
50	600	59·00	1,090	O	120	8	66	48	69	46	Mean test of 2 motors.
—	—	20·50	455	E	120	6	70	40	56	65	
—	—	20·50	447	E	120	6	73	51	57	82	

7. Open covered motors. The same as No. 6, but with a smaller cover made wholly or in parts of fine wire netting. The large area of wire-work prevents the tendency of any draught to cause the fine mesh to get clogged, and the motor fully loaded would be as cool as if unenclosed. This is specially adapted to textile mills where floating fluff is found.

8. Totally enclosed, but with forced ventilation like No. 4. This is necessary (*a*) when the motor is working in fumes very injurious to the motor, fresh air being sucked into the motor from a pure source through a pipe and discharged near the motor; (*b*) when the motor may be surrounded by inflammable gases, as sometimes in mines, the same air being circulated again and again through the motor and a cooling arrangement. Total enclosure with forced ventilation has been used to cool very large dynamos, cool air being drawn from outside the dynamo house and hot air discharged also outside.

The examples given in Table II. of the rise of temperature in motors open and enclosed are taken from records of ordinary tests in the workshop.

The motors were of the usual type, with decarbonised steel cases and laminated poles, the induction in the poles being from 13,500 to 14,500.

In most of the tests the motors drove another motor running as a dynamo whose current helped to drive the motor. Full particulars were taken every half-hour besides occasional temperature observations. All these are omitted so as to confine attention as briefly as possible to the rise of temperature.

The rise in temperature with the same motor with the same load in a given time is usually greater when the temperature of the atmosphere is higher. The rise in the temperature of the commutator in a given time under similar conditions can be considerably varied by differences of pressures, width and quality of the carbons, the best results being determined by experiment.

All the above motors had 4 poles. The particular figures of these tests apply only to the motors tested, but they are in general agreement with tests of other motors.

They show the reduced power permissible, if a motor be totally enclosed and continuously loaded. Below 3 H.P. the loss of power may be inconsiderable. But a 20-H.P. open motor when totally enclosed is but little more than equal in power to a 10-H.P. open motor. In the above table it is shown that a 50-H.P. open motor could only give 21-H.P. with a permissible temperature of commutator. To obtain the minimum temperature with the reduced output the winding had been specially arranged.

In short, whilst the power of a modern open motor is chiefly a function of its magnetic flux, when totally enclosed the power becomes a function of the area of its casing, considerably influenced, however, by its environment, that is, by the exchange of radiated heat with its surroundings, or the motion of the surrounding air.

The increased heating due to totally enclosing a large open type motor is strikingly shown by the following experiments and incidentally the increased iron losses due to high speed.

The motor was designed for 60 H.P. at 1,000 revs. per minute in the magnet case of a 50-H.P. motor at 600 revs. per minute. The ventilating slots around the periphery of the end covers were at first closed. This had been proved greatly to interfere with the ventilation of a large motor because a cylinder of hot air collects around the inside of the motor although both ends are open.

The armature was of the usual type diameter 410 mm., air-gap 3 mm. Slots 48, size 12 × 30 mm. The discs (which had the usual core holes) rested on the shaft 4 diameter. The magnetic flux was reduced about 15 per cent. as compared with the standard for 600 revs. per minute.

The armature was at first driven by belt from another smaller motor and the amperes noted. On running the armature, fully wound, but

with the magnets only excited, it was at once noticed that the increase of current on the small motor due to exciting the magnets of the 60 H.P. was much more than anticipated and that the armature rapidly heated. A series of progressive tests was then made to determine the iron losses. The results are shown in Fig. 2. These curves can only be approximate representations of the true iron losses as they include other losses which could not be measured. A similar armature but unwound was substituted and the tests for heating repeated with the same results.

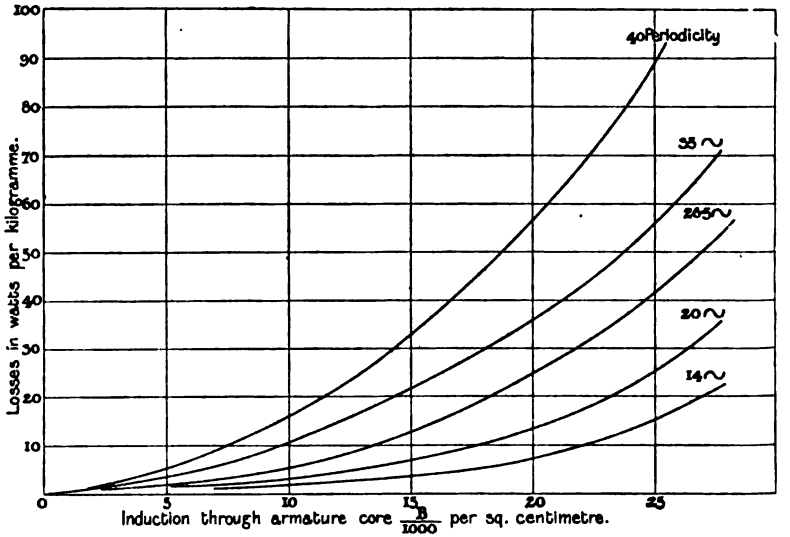


FIG. 2.

Iron losses in C. 500 armature at different periodicities.
Discs thickness 26 S.W.G. (*i.e.*, Standard Wire Gauge = 18 mils.) = 0·45 millimetre. They are coated with "Insuline" and rest on the shaft.
Weight of armature core, 81 kilogrammes.
Weight of armature teeth, 21 kilogrammes.
Mean section through teeth under pole-face section through core = 0·7.

The stampings were by Messrs. Sankey with "Insuline" paint on them.

The unwound armature was stripped and rebuilt, the stampings equally spaced by 10 sheets of tracing paper. On again testing, there was no noticeable improvement.

The armature discs were again removed, bored and fixed on a gun-metal bush—the end plates for supporting the end winding were turned thinner and the cylindrical part for supporting ends of the windings were made shorter and thinner. The end plates were also separated from the stampings by paper discs. This made a slight improvement after 2 hours' run with air at 60° F., the rise of temperature in the slots was 54 and in the centre of the core 66.

The heating being evidently due to the discs themselves, Messrs. Sankey were written to and they sent their curves for the iron losses which gave no calculated agreement with facts. Finally the armature was rebuilt with Stalloy stampings and tested unwound, but with the slots filled with wood and the magnets excited.

The results are shown in Fig. 3.

The rise of temperature in 2 hours was 8° F. less than before, showing a slight advantage over ordinary stampings.

The armature was wound and a fan fitted to the end of the armature to circulate the air inside. It was then tested as a totally enclosed motor, with a load of 58 H.P. for 3 hours, with the following results :—

Rise of commutator 111°.
Fields coils 88°.

It was again tested totally enclosed for 8 hours, but with a stop of 8 to 10 minutes every hour (after the first 4 hours) to take temperatures. Load 59 H.P.

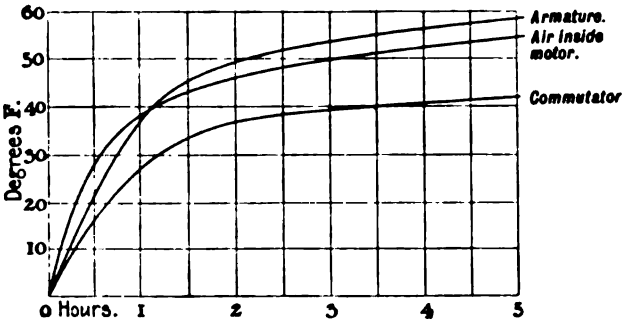


FIG. 3.—Heating on Test 60-H.P. Motor, 1,000 revs., Unloaded, Partly Open.

The final temperature rises were (air at 70° F.) : commutator 170, armature 149, field coils 125, air inside 105. There was not much increase of temperature after the first 4 hours, but the temperatures then were impracticable.

The fan was then removed and the motor ran at 59 H.P. as an open motor for 8 hours with the ventilating slots on the periphery of the end covers also opened ; the final temperature rise with the air at 62° to 69° was : commutator 58°, field coils 48°, armature 68° F. (see Fig. 4).

It will have been noticed from Table II. that the 50-H.P. motor totally enclosed at about 450 revs. per minute keeps reasonably cool with 20·5 H.P. This power probably would be the working limit at standard speed. The cooling surface of the totally enclosed motor per watt lost should be, apparently, not less than 3½ to 4 sq. in. ; but this depends on outside ventilation. On long tests the temperatures have often been known to go down after 3 or 4 hours, due apparently to draughts caused through opening doors.

The heating of the armature at high speeds beyond that given by the usual formula may be in part explained by the formula being founded on experiment that might be indicated by sine curves, whereas curves indicating the flux changes in the teeth and armature would be irregular, and show a greater maximum and far greater rapidity of change, at parts of a complete period.

Many measurements of temperature have been taken at intervals of 1 to 2 hours, necessitating stopping the motor tested for 5 to 10 minutes. On attempting to plot curves from these measurements showing the rise of temperature, it was obvious that there was a fall of temperature during each interval, especially in small motors, rendering the results of the test useless for the purpose intended.

The convex curve (Fig. 5) shows the gradual rise to a maximum temperature of an overloaded field coil of a dynamo (without an arma-

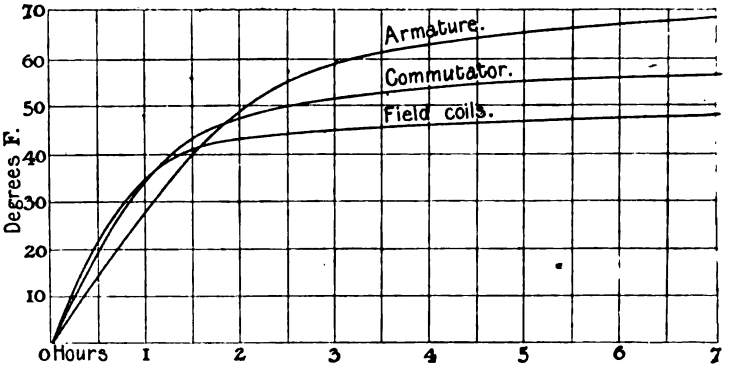


FIG. 4.—Heating on Test 59-H.P. 1,080 Open Motor.

ture) and the concave curve the shorter interval of time to reduce the higher temperature after the current is cut off.

Thus in this curve if any line A B C D be drawn A B represents the time required to rise to a particular temperature B E (measured outside the coil) and C D the time to cool. For the higher temperature which illustrates practical work C D is small compared with A B.

The dotted line shows the average internal temperature calculated from the reduced current as the temperature rose. The coil was fully exposed to the air, and it was noticed that the temperature between the coil and the magnet ring was the same as outside the magnet ring near the pole. In enclosed motors the outside of the case may at times be 20° F. cooler than the magnet coils inside.

The great advantage of intervals of light or no load in the cooling of loaded motors may be roughly judged from Fig. 6, which explains why heavy overload can be borne with intermittent work without undue heating, as in crane motors.

This advantageous cooling with intermittent loads can only be obtained when there is a considerable difference of temperature between that of the air and the highest permissible of the motor. If the air be very warm, so that this difference is comparatively small, the motor gets hot in less time than it cools. It will be seen on Fig. 5 that G H is less than K L.

It has often been noticed how a comparative small opening in a metal cover or (Class 6) enclosing an open motor would reduce the temperature. If the escaping air had a temperature of 72° F. only ½ the quantity given in table would suffice to carry off ½ of the heat, and if the velocity were only 2 ft. per second a moderate opening would suffice.

It may be noticed that there is no such thing as a gas-tight motor,

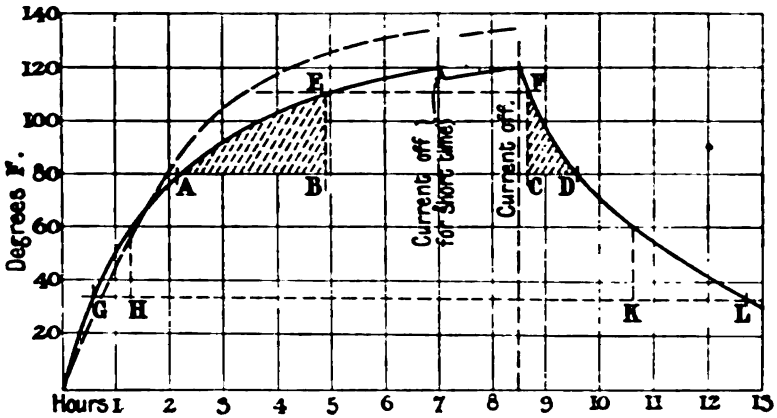


FIG. 5.—Heating and Cooling of a Magnet Coil.

even if the shaft worked through a stuffing box. The expulsion of, say, 15 per cent. of the enclosed atmosphere when it was heated and the entry of the same amount of gaseous air from the outside on cooling would cause the average condition of the atmosphere outside and inside soon to be similar. To enclose a motor tightly to keep out noxious gases is a delusion. Time forbids any detailed account of experience with the various ways of protecting motors.

In an explosive atmosphere they must be totally enclosed and strong enough to withstand an internal explosion as made by the author for a mine some eighteen years ago.

Experience with open motors exposed to various noxious chemical fumes shows that although the motor's appearance may be spoiled and soldered joints affected, yet the motors last so long that it is better to let them wear out and buy new ones rather than put up with the troubles from enclosing them.

In the author's opinion the reasons given for totally enclosing any

but very small motors (Class 5) are usually mistakes. In the case of insurance risk they tend to defeat the object in view.

In nearly every place where power is required for manufacturing, open motors may be used and easily protected against the real or supposed dangers of its particular environment.

Enclosed motors with a current of air forced through them either by

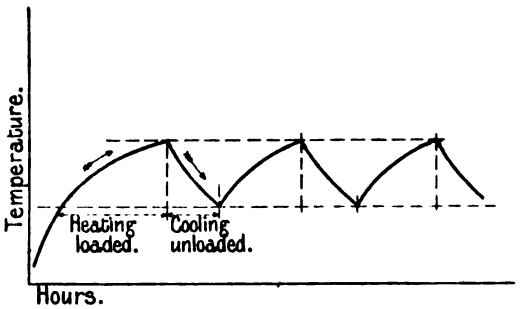


FIG. 6.—Intermittent Load.

means of a fan or chimney may be considered as open motors so far as heating is concerned.

In order that a continuous-current motor may give the least trouble, it is important that the arrangement be such as to keep the commutator as cool as possible and *vice versâ*.

The conclusion is that totally enclosed motors (Class 5) are under great disadvantages, and in general their use can be avoided.

DISCUSSION.

Mr. Churton.

Mr. T. HARDING CHURTON: It is a familiar fact that an electric motor, in common with any other apparatus that converts energy from one state to another, becomes heated in the process, and the question before us relates to the effect of this upon the temperature of the motor under different conditions which affect the rate at which the heat is dissipated. The quantity of heat applied is the equivalent of the watts lost in the motor, and the temperature to which this quantity of heat will raise the mass depends upon the length of time that it is applied, upon the specific heat of the materials, and upon the rate at which the heat is dissipated from the motor by radiation and conduction. On a uniform load the temperature will rise until the rate at which the heat is dissipated equals the rate at which it is generated, when it will remain constant so long as the same conditions prevail.

If the motor is enclosed all the heat must, of course, be radiated or conducted from the exterior of the case. If, however, the interior also of the motor is exposed to relatively cold air, the heat is more quickly carried off by the air; and the more rapidly the air is changed, that is

to say, the more perfectly that the motor is ventilated, the more quickly is the heat of the motor got rid of, and consequently the lower is the temperature attained. Mr. Churton.

With regard to Table I. the figures given appear to have but little practical value, at all events without further explanation. In the preceding paragraph, with reference to the time in which the temperature would rise 72° F., what is the meaning of the words "assuming that no heat escaped elsewhere"? Does this mean *other than from the exterior* of the frame, as in the ordinary case of an enclosed motor, and if so, have these results been checked by actual experiments? It is a simple matter to calculate through how many degrees of temperature a given mass of material of given specific heat will be raised by the application of a definite quantity of heat in a given time. But the essence of the matter under discussion is really as to the rate at which the heat of the motor is got rid of under various conditions which commonly obtain in practice.

With regard to the ratio of horse-power and area of enclosed motor surface, this is not only a matter of design, but is largely dependent upon the speeds of the motors; the slower the speed, the larger must be the motor, and consequently the greater area per horse-power and generally per watt lost. For example, a 50-H.P. motor at 1,000 revolutions per minute would be a much smaller machine than one of the same horse-power at, say, 200 revolutions per minute, and though the watts lost at the lower speed would usually be somewhat greater than at the higher speed (that is to say, the efficiency at the low speed would usually be lower than that at the high speed, though not necessarily so), yet the difference would not be nearly so great as the difference in the areas of the motor cases, and consequently there would be a greater area per watt lost at the low speed than at the high speed.

Now with regard to the paragraph at the bottom of page 491, the figures for the radiating surface per watt lost in small enclosed motors are confirmed by results I obtained from a 5-H.P. 2-phase induction motor, 50-~ 200-volt, 6-pole, short-circuited rotor; running at 5 H.P. as an open motor the temperature rise was 64° F. The motor was then run at the same power totally enclosed, when the temperature rose 75° F. in one hour, and reached 120° F. rise in four hours, at which it remained constant. In this case the radiating surface was equal to 1·65 sq. in. per watt lost, or, at this temperature rise, heat was being given off at the rate of 5 B.Th.U. per square foot per minute. The motor was then run at 3·25 H.P., a reduction in power of 35 per cent., the radiating surface being 2·35 sq. in. per watt, which resulted in a rise of 82° F., the heat dissipated being 3·49 B.Th.U. per square foot per minute. But the results which I have obtained in larger motors do not accord with Mr. Hartnell's. In the case of a 3-phase induction motor, 25-~ 500-volts, which, as an open machine, gives 60 H.P. at 480 revolutions per minute, was run at 34 H.P. totally enclosed at the same speed; the radiating surface was 1·45 sq. in. per watt, and the resulting temperature rise on a six-hour test was 72° F.

Mr. Churton.

I should explain that in this particular test—on four similar motors, each giving practically the same results—the horse-power was measured by the output of a dynamo which it was driving, but the watts lost are estimated, as the power factor was not observed. There may therefore be some slight error in the estimated efficiency, which is assumed to be 0·85. As, however, the motor was giving not much more than half normal load, the efficiency can scarcely be much higher, though if it really was so, it would, of course, make the area per watt lost a little greater.* It seems to me that if an enclosed motor is run long enough at constant load the entire surface will, in the absence of any disturbing cause, arrive at the same or nearly the same temperature, and that at a given increase of temperature above that of the surrounding air, other things being equal, heat will be radiated at the same rate, irrespective of the actual size of the surface. For this reason I cannot endorse Mr. Hartnell's statement that a large motor requires a greater area per watt lost than does a smaller motor for the same temperature rise.

Now with regard to the relation between the capacity of a motor open and enclosed. It is stated in paragraph 2, page 493, and in paragraph 6, page 495, that a motor that can be run at 20 H.P. open cannot, on account of heating, be run continuously at more than about 10 H.P. when enclosed. But in making this general statement the effect of the speed of the motor upon the comparison has not been taken into account. As I have already pointed out, in dealing with the ratio of horse-power and area of surface, that usually the area per watt lost increases as the speed is reduced, consequently the difference which is made in the effective power for continuous work by enclosing is much less in slow- than in high-speed motors.

Table II. gives some comparative results in horse-power, speed, and temperature rise obtained from certain motors, but unfortunately the watts lost in each case and the radiating surfaces per watt lost are not given. A comparison of the watts—or rather the equivalent in calories or B.Th.U.'s per minute—dissipated and the temperature rise attained when open and enclosed would be in fact a measure of the efficiency of the ventilation of the motor.

I should remark that whereas the tests from which I have taken my figures have been on alternating-current motors, those from which Mr. Hartnell has obtained his have been direct-current machines.

Mr. Chapman.

Mr. F. T. CHAPMAN: I entirely agree with Mr. Hartnell's conclusion as regards the enclosing of motors. I think by protecting them in various ways we protect them more from the attendant than from anything else.

The method of cooling given as 8 (*b*) on page 494 would appear to be under the same disadvantage with respect to gradually drawing in the surrounding gases as is pointed out later in the paper in the case of

* The maximum probable error would make this 1·6 sq. in. The temperature rise was probably affected by cold draughts in the engine-room in which the tests were made.

an ordinary totally enclosed motor. An attempt has recently been made to solve this problem by the use of the safety lamp principle. The gases are allowed to circulate through the motor, but the openings through which they are drawn in and expelled consist of tortuous passages exposing a large amount of cool conducting surface, and thus preventing an explosion occurring in the motor from igniting the gases outside. Mr. Chapman.

The curves given in Fig. 2 emphasise the impossibility of getting accurate results by this method; for instance, at B-25,000 the difference between the loss at 20 ∿ and that at 26·5 is greater than that between 26·5 and 35. The losses at these high densities appear to be practically proportional to the square of the density and to the square of the frequency, and must be almost entirely due to eddy currents.

The watts lost per square inch of case determine the rise in temperature of the case itself. The temperature of the internal parts will be higher than that of the case by an amount which depends for any part on the watts lost in it, and on the effective conductivity of the space between it and the case.

Mr. W. B. WOODHOUSE: Mr. Hartnell's tests show very clearly in Table II. the variation in temperature rise of different parts of a motor when open and when enclosed. They suggest the unsuitability of a standard open type motor for conversion to an enclosed one. With an open type motor certain parts of the motor are kept down to their working temperature by the windage. When the motor is enclosed that windage no longer has effect, and these parts of the motor will get unduly hot, and eventually the whole motor will heat up to a higher temperature. One is inclined to agree strongly with the latest practice in dynamos—in the largest ones, at any rate—where the machine is completely enclosed, but provided with forced ventilation, the air being drawn in from outside through an air duct and delivered through another air duct to the outside again. This is treating the problem of ventilation scientifically, while the older method is a somewhat haphazard one. Mr. Woodhouse.

I was interested to notice recently a description of an installation in a textile factory where a large number of spinning frames were driven by totally enclosed motors. The motors drew air from a ventilating duct in the floor in direct communication with the outside of the mill, and discharged the heated air into another duct. The design strikes one as being a very good one, as the fluff and dust flying about does not get to the motor, which is properly and uniformly cooled.

The fire insurance offices some time ago issued regulations as to the enclosing of motors in textile factories, insisting that the open-type direct-current motor was dangerous and should be totally enclosed, but the alternating-current motor need only be enclosed by wire netting or perforated sheets with ¼-in. openings. My own experience is that such perforated sheets do not alter the rating or heating of the motor at all.

Professor G. D. A. PARR: The author mentions on the first page the Prof. Parr

Professor Parr. improvements made in motors in recent years, and amongst these it is pointed out that magnetic leakage has been reduced to a quarter to one-fifth of that in the old ring-wound motors. I was under the impression that the old ring-wound motors had a leakage coefficient of 1·35 or 1·4, and I was not aware of the fact that the present day motor could be made with any smaller leakage coefficient than 1·15. I should like to know whether that is a misprint or whether I am in error.

At the bottom of page 491 he states although 2·5 to 2·0 sq. in. of radiating surface per watt lost may suffice for small enclosed motors, considerably more would be necessary to keep, say, a 50-H.P. enclosed motor equally cool. I rather think this must be a mistake, because it is in direct contradiction to the last figure of Table I. (column 4), which states that the cooling surface per watt lost is practically 2½ times less in a 100-H.P. motor than in the case of a 3-H.P. motor. It is possibly meant that the total amount of surface must be more.

On page 497 he refers to the substitution of Stalloy stampings for the ordinary metal. I would rather like to know whether the thickness of these Stalloy stampings was the same as that used on a previous shaft in the test alluded to. I was under the impression that Stalloy gave very good results as regards losses in it, but the results do not seem to confirm this.

Mr. Cridge. Mr. A. J. CRIDGE: An unusual instance of the heating of an alternating-current motor came recently before my notice. The manufacturer—from motives of economy of space, perhaps, or of material—had covered the stator stampings with a thin sheet of iron, held in position by grooves in the end castings. The outside of the motor became very hot, and the user sent for us to see if anything was wrong. It was found that the temperature of the sheet varied considerably at different points on it, and further, that the temperature of the windings was much less than that of the outside. We therefore assumed, although we had no direct evidence, that the heating of the cover was due to eddy currents in the thin sheet. I do not think this solution occurred to the manufacturer, for he put in a fan at one end of the motor, which had the effect of cooling one side and leaving the other as hot as ever. It also had the effect of drawing the oil out of the bearings and throwing it into the stator windings.

With regard to the enclosing of motors, it is satisfactory to notice that Mr. Hartnell thinks that, as a rule, it is useless. Some years ago a 3-H.P. induction motor was installed in a textile factory, and the insurance company's representative insisted that the motor should be entirely enclosed. Apparently the danger he apprehended was sparking at the brushes, which, as the motor was of the squirrel-cage pattern, were, of course, non-existent. However, he caused the user to cover it up with an iron box, and the result was that no air could get to it at all, and the motor was always hot.

Mr. Mylan. Mr. W. F. MYLAN: On page 492 there is a rather remarkable statement. Mr. Hartnell says, "In order that the radiating surfaces be most

efficient they must be opposite to cool surfaces, as all surfaces radiate heat in all directions." I have always understood that the radiation of surfaces depended entirely on the temperature difference between the radiating body and the surrounding media, modified, however, by the heat radiating surface, that is, whether polished, dull, black, or white. Mr. Mylne.

On page 494, Table II., we get two sets of readings—standard and tested. Some of them seem rather curious.

In the first instance there is a 3 H.P. with standard as 1,250 revs., but the speed when tested is given as 1,080 revs. Other illustrations having similar divergence between the standard and tested speed are given. It would be interesting to know whether the machines are electrically and mechanically duplicate, and whether the difference in speed was obtained by brush rocking or by different field winding. One would expect with an enclosed motor, otherwise duplicate of the open motor, that with the same field and armature winding a much higher speed would be obtained owing to the temperature rise of the machine and consequent increased field resistance and reduced field current.

I wish we had more of the users present to hear the author's remarks regarding non-necessity for totally enclosing motors. We should, I am sure, have fewer such machines installed, and consequently we should have fewer complaints of faulty machines. I find, without exception, that totally enclosed machines are liable to be badly neglected, and are often allowed to run under conditions the reverse of satisfactory.

Mr. H. C. JENKINS: During my experience with motors in mines, I find the tendency among many mining people to install totally enclosed motors is becoming less general, and in many cases they are using open-type motors, making arrangements so that contact with fiery gases is obviated. The question of putting very fine wire gauze over the motor, on the principle of the Davy lamp, might be a good idea for mills, but is hardly an ideal thing for a colliery, as the coal dust will choke up the small apertures and the motor would be running therefore as a totally enclosed machine, unless the gauze is cleaned frequently. Mr Jenkins

I know of one instance of an electric haulage where the haulage house is situated near to the up-cast shaft, and there is a good deal of gas present at various times. They have arranged to have the front of the haulage house enclosed, with a window so that the man can see the roadway, and the only openings to the return air shaft, by means of which gas could enter, are two slots where the ropes go through. A pipe brought from the up-cast shaft allows the fresh air to play directly on the resistance and the motor, and as there is a certain amount of air-pressure in the haulage house there is no chance for the gas to get in.

The risks they have to undergo render the adoption of enclosed-type motors in gassy mines undesirable.

Mr. F. M. MOODY: I agree with Mr. Hartnell that wherever possible the use of enclosed motors is to be avoided. Some, after a few Mr. Moody

Mr. Moody. hours' run, are little better than cooking stoves, but in spite of this defect it is the best of the various types for direct coupling, all the working parts which are liable to injury being enclosed. For driving line shafting or steady loads, through the medium of a belt, I certainly favour the entirely open type in preference to any of the others. In motors of the open type the attendant can see what is happening at the brushes. With an enclosed motor the brushes and commutator are neglected to a great extent; the motor revolves, and what happens inside the case is to a great extent neglected. It is due to this fact, more than the heating, that the open type is to be preferred.

The majority of enclosed motors in a works run under conditions as shown in Fig. 6, and such motors can take up heavy overloads for short periods without undue heating.

In the paper Mr. Hartnell has taken the heating due to the eddy currents but has given us no information on the higher temperature of the windings due to the heavier insulation used in the modern machines. The heat produced is no greater, but is the dissipation of the heat so produced so good? If it is not, then this will have an effect on the temperature rise, and at a point where the temperature ought to be kept low, that is, in the windings.

The question with these enclosed motors is, does the higher temperature cause the insulating material to deteriorate more than with the lower temperature obtained with the open-type motor? With a temperature rise of 100° F., will the motor have a longer life than if the temperature rise is 120° F.? At the Sheffield meeting of the Section in 1906, Mr. Raworth gave it as his opinion that, providing the safety limit was not exceeded (the limit to the temperature rise he put at not less than 212° F.), the danger of a burn out was not greater with the higher temperature. If this is the case the objection to this extra heating is not so serious. Personally I object to these high temperatures.

A great deal can be done to insure cool running by the design of the commutator and armature end connections so as to produce a draught through the armature, apart from the addition of a fan on the armature. The use of interpolars tends to reduce the cooling effect in the armature, such machines at the same time showing a higher rise in temperature, due to the smaller section of the iron, and Mr. Hartnell's experiences in this direction would be valuable if he would give us information on this point.

Mr. Hartnell. Mr. WILSON HARTNELL (*in reply*): In reply to Mr. Churton, Table I. may be explained as follows: Column 1 is the nominal horse-power of an actual set of specially designed motors, the speeds of which are as follows:—

Speeds	1100	1000	900	850	800	750	700	600	550	500	450
H.P....	3	5 & 7½	10	15	20	30	40	50	60	75	100

Columns 2, 3, and 6 are taken from tests and measurements of these motors, except that the figures are averaged by means of the curves

Mr. Hartnell.

shown on Fig. 1. The watts lost at full load on the four larger motors are calculated. Column 4 is derived from columns 2 and 3. Columns 5 and 7 are calculated to enable one roughly to estimate the cooling effect derived from ventilation or from the mass of the motor. The contents of Table I. are graphically shown in Fig. 1.

Mr. Churton remarks that a slow-speed motor has a greater cooling surface than one of the same power of a higher speed, and therefore the loss of power on enclosing a slow-speed motor is proportionately less; this is so, as may be readily seen by his examples. I made no reference to this effect of speed in order not to wander from the title of the paper, which has no direct bearing on the increased cost of low-speed motors. It is convenient to standardise former windings and armature windings, so that by their combinations other speeds and voltages may be obtained. For these particular motors four speeds have been tabulated for each size for four different voltages, giving 192 combinations. The watts lost on each combination could have been given, but this would have been another subject. The nearest sizes to Mr. Churton's examples of enclosed motors are a 3-H.P. tested at 2 H.P. with 780 revs., and a 50-H.P. tested at 20·5 H.P. with 455 revs., and an experimental test of a 50-H.P. at 60 H.P. with 1,090 revs. The cooling surface being obviously considerably more for a slower motor than with the standard case. It was necessary for the sake of comparison to take motors at about standard speeds, and as the speeds of the motors taken are nearly in accordance with those recommended by the Engineering Standards Committee, it may be assumed for the purposes of this paper that they are about the most advantageous for direct-current ventilated motors.

One reason why a large direct-current motor requires greater cooling surface than a smaller one and a direct-current motor more than an alternating-current motor is because of the difference in the thickness of the case. The alternating-current motor is placed in an iron case as thin as can be conveniently cast; it may have been ⅛ in the alternating-current motors with which Mr. Churton experimented. The case of a direct-current motor is its yoke. That of the 3 B.H.P. alluded to in this paper is ¼ thick and that of the 50 B.H.P. 1¼ in. thick—from two to five times the thickness of the alternating-current motor. That an alternating-current motor case should radiate one watt for 1·65 sq. in. with the internal air temperature at 120° F. agrees with my experience, but that a watt should be radiated through 1·45 sq. in. with a difference of temperature of only 72° is surprising.

In reply to Professor Parr, it is an inference from tests of motors with laminated poles and small air-gaps that the magnetic leakage may be as small as 7½ per cent. The cooling surface per watt in Fig. 1 is the surface available, if the motor were enclosed and working at full power. It is not the surface that would be required to keep the motor reasonably cool. The Stalloy stampings appear of small advantage for direct-current motors.

Mr. Hartnell.

In reply to Mr. Mylan, the heat lost by radiation only is the difference between the heat radiated and the heat received by radiation from surrounding surfaces irrespective of the temperature of the intervening air. The motors tested at reduced speeds to which he refers had longer armatures, but the standard cases.

In reply to Mr. Moody, I note that he is in complete agreement as to the advantages of open-type motors over enclosed motors. In Table II. he will find the rise in temperature of the field coils given in column 9. There is no necessity for thicker insulation on the magnet coils, as the difference in voltage from layer to layer is no greater than with the old 2-pole motor—in fact it is less, as the coils are shorter. In general, if the total external cooling surface of the coil is about 4 sq. in. per watt lost and the motor well ventilated, the rise in temperature will not exceed 72° F. In regard to the highest permissible temperature on magnet windings, experiments are needed. The temperature of boiling water could not hurt the cotton, the only inconvenience being that the speed is much higher than when the motor starts cold. The sparking limit becomes reduced when the temperature rises, say, above 130° F. If the temperature rises over 150° it is likely to give trouble. The fan effect of connectors on the commutator, although most useful in an open motor, is not of much assistance if the motor be enclosed. It appears to me that only those who have attempted the design of totally enclosed motors of large power have any idea of the difficulties to be overcome; in fact, they seem almost insuperable without forced ventilation.

In reference to Mr. Cridge, the sheet-iron case is applicable to alternating-current motors provided it is made sufficiently roomy.

The instance which Mr. Woodhouse referred to, wherein the motors are enclosed but fixed over an air duct, is, I consider, the true way of dealing with enclosed motors.

ELECTRIC STREET LIGHTING.

By W. F. LONG, Associate Member.

(Abstract of Paper received from the CAPE TOWN LOCAL SECTION, *October 28, 1907.)*

The problem of street lighting, more especially in the old country, has probably received more attention during the past two years than at any time since the advent of either coal-gas or electricity as a means of providing a public luminant. Apart from receiving the careful study of public bodies responsible for the lighting of the streets, and the rival supply companies of electricity and gas, it has at the same time formed the subject of several papers read before the various scientific bodies.

Until recently the open or enclosed type of electric arc for main streets had no serious competitor, the increased illumination over incandescent gas being so great in comparison with the increased cost, if any. The gas companies, however, have made a bold effort to recover lost ground by the introduction of high-pressure gas.

About the same time the flame arc lamp made its appearance, and wherever the efficient lighting of main thoroughfares is under consideration to-day, the flame arc lamp is an easy favourite.

Latterly, however, it has been realised by many that in the first place street lighting is undoubtedly a good advertisement for the supply company; and secondly, that too much attention had been given to the inconvenience of street lighting being required just at the peak of the load and the necessity of increasing the plant to meet the same, whereas not sufficient attention was being paid to the extremely high load factor possessed by street lighting.

Main street lighting, and the majority of tramway routes other than interurban, should undoubtedly be lighted by some form of arc lamp. Where possible, whichever type of lamp is used, they should be preferably placed in the centre of the road, there being no doubt whatever that such a system gives far more efficient lighting than the use of side lamps. If placed on tramway poles of centre-pole construction work, they should be provided with some form of flexible suspension, otherwise the constant jarring effect of passing trolley wheels has a very detrimental effect on the working of the lamps. There are several forms of this safety gear on the market.

Opinions differ regarding the trimming of street arc lamps, many engineers preferring the use of a ladder or even a tower wagon.

Personally, I see nothing against the use of the safety suspension, as provided the right type is used and proper care is taken by the trimmer that the gear is locked before he leaves it, the falling of a lamp is practically impossible. Certainly the labour saved in trimming considerably outweighs the extra first cost of providing the gear.

Of the type of arc lamps available for street lighting, although the open and enclosed are steadier in their burning than flame lamps and cost less for carbons per lamp per hour, it must be borne in mind that all flame lamps are far more efficient, many are very reliable, and from my experience in some cases the unsteadiness is due to outside influences.

The controlling of arc lamps at the power station should, however, be carried out as much as possible, as it is this saving in operating expenses which allows of more successful competition with gas. It can be managed up to a certain degree by supplying those circuits nearest the power station direct from the busbars instead of from the distributing mains in the street. The switching on of the whole arc-lighting system can, moreover, be entirely and satisfactorily controlled from the power station even when the lamps are supplied from various points of the distributing system if magnetic switches are used controlled by pilot wires.

I am informed that in Glasgow, owing to workmen loitering over switching lamps off at 2 o'clock in the morning, and to the time taken to get round the whole system, a scheme was devised which is known as the Glasgow Arc Lamp Starter (Lackie, Calderwood & McEwen's Patent), and for those not conversant with this system a description would, perhaps, not be out of place. The system is designed with a view to controlling all the street arc lamps from the power station, and at the same time accomplishing this with as little expense as possible in the provision of pilot wires, still allowing an interval of time between the switching on of each group.

The arrangement consists of three pilot wires run from the station, two of which control the magnetic switches, the third being used to light a lamp at the station when all circuits are switched on, a second lamp being provided which also lights up when all circuits are off. Each bank of lamps consists of 20—two circuits of 10 in series on 500 volts—and there are twelve banks, namely, 240 lamps in all. A small switchboard fixed in the station contains the switches A and B, a milliameter, and the two incandescent lamps referred to above.

To start the lamps switch A is closed; this energises the solenoid of an auto-switch on a street pillar near the first bank of lamps and pulls up the main switch, putting current on to the lamps. The closing of this switch lifts a brass ball which is free to roll down a spiral path, at the end of which it closes the pilot wire circuit to the switch controlling the next bank of lamps, where the same performance is repeated, and so on, until all the eleven banks of lamps are switched on, when the pilot lamp in the station lights up. The time taken by the ball to run the full length of the spiral path is 10 seconds. During the progress

of switching-on the milliameter rises step by step as the various switches are operated, each step being two-fifths of an ampere.

When all banks are on, the switch A is opened, thus saving the energy used by the magnetic switches, the switches being meanwhile held in mechanically by a trigger.

To switch the lamps off, switch B at the station is closed, energising the second solenoid in the pillars, tripping the triggers, and opening all main switches, when the second lamp at the power station lights up.

The following is claimed in connection with the use of this apparatus.

Saving in Cost of Arc Street Lighting due to the Use of Arc Starters.—Take 850 street arc lamps.

Men Employed without Starters.

11 men at 27s. per week
1 man at 24s. „
11 men at 21s. 5d. „
} £27 16s. 7d. per week, or £1,446 16s. 6d. per annum.

Men Employed with Starters.

16 men at 27s. per week (average), £21 12s. per week, or £1,123 4s. per annum.

Saving per annum in favour of starters, £323 12s. 6d.

Units Saved by Using Starters.—The switching-in need not be started so early, or the switching-out completed so late, as when men have to go the round of lamps. Taking the time of burning on this account as ½ hour less per day, lamps taking 500 watts or ½ B.O.T. unit per hour, the units saved will be $850 \times \frac{1}{2} \times \frac{1}{2} = 212{\cdot}2$ units. At 1d. per unit this would amount to, say, 17s. 8½d.

Also 12 pairs of carbons would be saved. At 1s. 3d. per 12 pairs, this would amount, together with the cost of setting and trimming them, to 2s. 3d. per day.

Therefore total saving is—

17s. 8½d.
2s. 3d.
} = 19s. 11½d., *i.e.*, £364 4s. 9d. per annum.

	£	s.	d.
Total saving (men's time)	323	12	6
Current, carbons, etc.	364	4	9
	£687	17	3, say £688.

Allowing one starter to 10 lamps at £10 each installed, taking depreciation at 7½ per cent., interest 5 per cent., and sinking fund 2½ per cent. per annum, makes £127 10s. on £850 capital. Deducting this annual amount from £687 17s. 3d., leaves £560 7s. 3d. net saving on 850 arc lamps, which is equivalent to 13s. 2d. per lamp per annum.

There is not a great deal of street arc lighting in Cape Town, but, with the exception of Darling Street, it is controlled either from the central power station or the accumulator station.

A series of flame arc lamps has recently been installed in the Dock Road, and in view of the entire absence of flame lamps in Cape Town until these were installed, I propose to deal somewhat fully with this installation.

The lamps used are the now well-known Oriflamme type, manufactured by Messrs. Oliver & Co., of Woolwich, and contain several novel features, the foremost of which is the provision of a magazine by means of which the lamps are supplied with eight pairs of carbons, the second pair being automatically brought into action when the first pair are consumed, likewise the third pair when the second are consumed, and so on; the lamp is thus only trimmed after thirty-five hours' burning.

An inspection of the lamp will show that the feeding of the carbons from the magazine is accomplished by means of an endless chain revolved by a pawl and ratchet, the former being actuated by an electromagnet. This electromagnet is operated by a shunt coil, which is momentarily put in series with the shunt winding on the main coil of the lamp when it is time for the feed to take place. A novel feature in connection with this feeding coil is the switch, which, it will be noted, is an evacuated tube containing mercury and pivoted at its centre so as to allow of a rocking movement. On the arc reaching the position where feeding should take place, the tube is tilted sufficiently to allow the mercury to flow the whole length of the tube, to the ends of which are connected the feeding coil. The magnet then lifts, and, as before mentioned, works the pawl and ratchet motion, the lifting of the magnet itself rocking the switch back to the off position.

In spite of the fact that these switches are continually opening and closing the circuit, they last quite a long time, but eventually the glass is cracked through the continual mercury hammer, when, of course, the switch soon becomes useless, due to the loss of vacuum.

Another unusual feature of the lamp is the low voltage required, the pressure across the terminals being only 34 volts, which allows of 11 lamps being burned in series across 440 volts.

The normal current is 9 amperes, each lamp therefore consumes 306 watts, and the mean candle-power in the lower hemisphere is stated to be 1,300.

As a matter of fact, we find that these lamps give much better results with 10 amperes. The energy consumed on the circuit, including line resistance, is therefore 4,400 watts, giving a total candle-power of 14,300, and costing at the current price for street lighting in Cape Town 0·0016d. per candle-power per hour, including all labour and materials for trimming and general maintenance, together with interest charges on the capital expenditure in providing and installing the lamps.

The lamps are placed in Hyde Park carriers on tapered steel poles placed in the centre of the roadway, the whole of the wiring being carried out by means of No. 4 S.W.G. bare wire carried on insulators attached to the poles.

Owing to the exceptionally long spans, 210 ft., and to the fact that at the time heavier poles could not be obtained for the ends of the line, it was not possible to run two wires of the above section on the lamp poles themselves, the return wire is therefore attached to the poles at the side of the road carrying the ordinary 3-wire distribution system.

In addition to the flame lamps, each pole also carries a double bracket fixed about 12 ft. 7 in. from the surface of the road, each bracket containing two 110-volt 25-c.p. tantalum lamps in series, which are, of course, wired on a separate circuit. The overhead wires in this case being No. 12 S.W.G. are attached by means of insulators to the sides of the Hyde Park carriers, so that the only wire causing a shadow with the arcs is the one No. 4, and this, I may say, is hardly noticeable. Both the arc and tantalum circuits are controlled direct from the generating station.

Turning now to the question of side-street lighting. Some twelve months ago a trial was made with 25-c.p. 110-volt tantalum lamps on an extension to our street-lighting system, and as the illumination required per pole was not to exceed 25 c.p., these lamps were installed by running series overhead wires between poles. The lamps proving very satisfactory and being seldom reported as not lighted, steps were taken to change the majority of the carbon filament street lamps for tantalums, so that now quite 80 per cent. of the street lighting is carried out in this manner.

The 25-c.p. 110-volt tantalum lamps take on an average 0·2 of an ampere; a No. 14 S.W.G. bronze wire has ample carrying capacity as the series wire, even if, as in some cases, the lamps are a considerable distance apart.

As an instance of the saving that can be effected by this lamp, I should state that the cost of street lighting in Cape Town has been reduced this year by 33⅓ per cent., although some 300 additional side-street lamps and about 20 arc lamps have been erected, whereas the charge per unit for energy consumed for street-lighting purposes has only been reduced by 12 per cent.

The only personal experience I have had with osram lamps for street lighting up to the present was obtained in September of last year, when I received two samples which were placed on a street-lighting circuit.

These lamps were marked 110 volts 32 Hefner candle-power, and gave an initial candle-power on the photometer of 27 English candles with a consumption of 36·7 watts, or 1·2 watts per candle. A second test was made after 374 hours, when the figures were 25·1 c.p. at 1·5 watts per candle. A third test after 504 hours gave 23·5 c.p. at 1·6 watts per candle.

The Cape Town City Council has been successful in obtaining the street lighting of Woodstock in competition with the local gas company. The work in connection with this scheme is now in course of construction.

The distributing system will be entirely overhead and carried out

on a 3-wire system similar to Cape Town, with 440 volts across the outers. The lamps to be erected comprise 300 in number, and will consist of two 110-volt 32-c.p. Hefner, osram lamps, in series in one fitting. The energy required will be transmitted from the power station in Cape Town to the boundary of Woodstock and Cape Town by extending an existing 0·4 sq. in: concentric feeder; the feeder being also used for the supply of energy to private consumers until such time as the loads warrant the use of a sub-station. The overhead distributing system entails the use of some 300 poles and 35 miles of bare overhead wires, the whole to be completed by the 1st of January, 1908, when the five years' street-lighting contract commences.

The following particulars are useful as a guide to the possibilities of street lighting locally by means of metallic filament lamps as against incandescent gas.

One suburban municipality is paying to-day £7 per 60-c.p. incandescent gas lamp per annum for 2,000 hours burning. A recent quotation to another suburban municipality was £6 10s. per 55-c.p. incandescent gas lamp per annum for 2,000 hours burning.

The average various tests of gas mantles made in recent years prove that they take 0·1 cub. ft. of gas per candle-power per hour, which information, together with the above, gives the following comparative table for gas and metallic filament lamps :—

System of Lighting.	District.	Candle-Power.	Charge per Lamp per Annum.	Hours Burning.	Cost per C.P. per Hour.	Energy Consumed. Gas Cub. Ft. Electricity Units.	Cost of Energy. Gas per 1,000 Cub. Ft. Electricity per Unit.
			£ s. d.		d.		s. d.
Incandescent ...	Sea Point	60	7 0 0	2,000	0·0140	12,000	11 8
Incandescent ...	Woodstock	55	6 10 0	2,000	0·0141	11,000	11 9
Tantalum Electric	Cape Town	25	2 18 2	3,000	0·0093	127	5½
Osram Electric	Woodstock	50	5 10 0	2,000	0·0132	125	10½

The column "Cost of Energy," of course, includes both interest charges and maintenance. The Woodstock figure of 10½d. per unit is high, owing to the fact that the whole of the capital expenditure entailed has to be repaid in five years.

ORIGINAL COMMUNICATION.

ON THE MEASUREMENT OF LARGE INDUCTANCES CONTAINING IRON.

By Sir OLIVER LODGE, D.Sc., F.R.S., Member, and BENJAMIN DAVIES, Associate Member.

(*Received March* 17, 1908.)

The advantage of inserting self-inductance in telegraphic lines, especially in lines rendered inefficient by electrostatic capacity like submarine cables—an advantage first discovered and advocated on theoretical grounds by Mr. Oliver Heaviside, F.R.S.—is so marked that a number of investigations have been conducted by the electricians of the Eastern Telegraph Company in the research laboratory in Electra House, and the second-named author, Mr. Benjamin Davies, who has been allowed to work there for the last few years. Most of the results must be regarded as confidential and of specially technical use, but some of the methods of measurement are of general scientific interest, and these we propose briefly to describe.

The self-induction coils involved are, some of them, of considerable magnitude, rising to an inductance approaching 100 henries; and for compactness, as well as to avoid mutual inductive interference, it is customary to make them with iron cores forming a nearly closed magnetic circuit. An air-gap is, however, introduced into this circuit and is made variable at will, since one convenient adjustment for duplex telegraphy is the variability of the gap in a continuous and convenient manner by an outside screw handle.

The inductance of such a coil depends, of course, greatly on the width of the gap, and it is also a function of the strength of current circulating round the iron; accordingly the measurement of its self-induction, though an important measurement, is not an easy one, when the alternating current involved in the measurement is reduced to 10^{-4} or 10^{-5} amperes, and special means have had to be devised. It is these in particular to which the present communication relates.

The usual methods of measurement were tried, but were found to give inconsistent results, and were at best laborious, involving much time. The only safe method of measuring the inductance of iron coils is to reproduce in the measurement as far as possible the conditions of practice; otherwise the results would subsequently be misleading.

The difficulties arose partly from the presence of harmonics, introduced by hysteresis when the magnetising forces were great, partly also from magnetic creeping, which was very troublesome in closed or nearly closed iron magnetic circuits even when the current was

small. Further difficulties arose from the fact that the inductance varied with the frequency of the current alternations, and they were emphasised by the enormous time constants which some of the coils possessed; the time required to rise within 1/*e*th of the ultimate value being in some cases as much as 4 seconds.

The present paper describes a simple and ready method of using a special sine inductor and dead-beat galvanometer so as to determine simultaneously the value of the inductance and the strength of current involved in the operation.

Telegraphic Preliminaries.

The ordinary measuring instruments, such as a hot-wire meter, give the square root of mean square strength of current; but unless the wave is strictly sinuous such a measurement is not useful. For strong magnetising forces a number of harmonics make their appearance, and the disturbance is far from sinuous; and even for weak magnetising forces it would not do to assume that the harmonics are negligible.

It is found to be the fact, however, that they are unimportant for weak forces; and hence for small strength of current, such as those at the receiving end of a long cable, a hot-wire instrument giving $\surd$(mean square) values of current might be used. But for all other cases the amplitude or maximum value of the magnetising current normally used must be directly observed, and the maximum value thus found must be reproduced in the operation of measuring.

The currents supplied to a cable can be represented as being due to sudden rises and falls of E.M.F., but by the time they reach the distant end they have become approximately sinusoidal; in fact, the currents representing the signals at the end of a cable of moderate length may always be regarded as composed of sinuosities with three frequencies, n_1, n_2, n_3. Of these n_1 and n_2 are always in the ratio 1 : 2; while the third n_3 is a low irregular frequency superimposed on n_1 and n_2.

The first frequency (n_1) corresponds to regular reversals at the sending end—that is, to dots and dashes, or right and left deflexion, alternately; as, for instance, the letter C on the Morse Code.

The second frequency (n_2) corresponds to the case of a succession of impulses all of the same sign, a series of dots, or a series of dashes: as illustrated by the letters S, H, I, or the letters O, M; or, again, by component parts of other letters, like part of B.

It is this unidirectional sending which tends to charge the cable and so cause a slow fluctuation of zero which represents the third frequency n_3. About this there is nothing regular, but it is always much slower than the others, and ought to be eliminated and carried off to earth, along with earth disturbances, by a coil of low resistance but high self-induction which is arranged to shunt the receiving instrument; this elimination being assisted by the obstruction offered by the receiving series condenser.

In practice the second frequency—the sinuosity representing a succession of dots—is not needed in practical telegraphy. The holding

over of the siphon for a definite length of time is sufficient to enable a practised reader, or even a moderate novice, to discriminate between *i* and *s* and *h*, without the need of the actual minor sinuosities; and inasmuch as this highest frequency is usually obliterated in long cables by the more marked attenuation appropriate to higher frequencies, they do not as a rule appear, except when they are definitely wanted.

A diagram of the first few of the letters of the alphabet will illustrate what is here meant.

Fig. 1 shows the theoretical letters as they would appear if slowly recorded at the end of a cable. The letter A in this figure is a complete wave, and the letter C also is sinuous with the main frequency n_1. In practice the frequency n_1 usually lies between 3 per second and 15 per second.

The letter H, or the three dots of the letter B, due to unidirectional impressed E.M.F., are also represented by a sine curve, but in practice are of double the n_1 frequency.

The third frequency (n_3) depends on the sequence of the signals, and its average value is about $\frac{1}{10}$th the frequency of the letter A.

The three waves are—

$$v_1 = a_1 \sin pt.$$

$$y_2 = a_2 \sin 2pt + C.$$

and approximately $y_3 = a_3 \sin \frac{1}{10} pt.$



FIG. 1.



FIG. 2.

The attenuation of signals is such that a_3 is practically obliterated at the distant end, and matters are so arranged mechanically and electrically in the recorder circuit that this frequency is never useful: it is generally killed by a few hundred miles of cable, at moderately high speeds of signalling. Fig. 2 shows the above letters as they would appear in practical telegraphy. We are therefore left with the frequencies n_1 and n_2. These together govern the design of most of the inductances used for submarine telegraphic purposes.

The method of measurement described below depends on the use of a galvanometer for observing the maximum amplitude of the alternating current involved in the operation. Having designed a maximum-amplitude galvanometer to give the required sensitiveness and quickness, the measurement of all iron inductances of large time-constants can be made with ease.

DESCRIPTION OF THE GALVANOMETER.

The instrument consists of a moderately strong electromagnet of adjustable strength, the field of which can be pushed up to about

8,000 C.G.S. The magnetic circuit is all iron except the narrow gap in which the coil is placed. The coil has about 500 turns wound on a light aluminium frame 4 cm. long and ¼ cm. wide. The oscillation of the coil is measured by means of a mirror and a spot of light; but the mirror is mounted, not on the coil in the usual manner, but on a saddle suspended independently and connected to the coil by a couple of silk fibres, after the same fashion as the siphon of the siphon recorder is connected. The object of this method is the magnification of the motion of the coil mechanically.

The arrangement of coil and mirror is shown in Fig. 3. It is the usual arrangement of the coil and siphon of the siphon recorder.* The mechanical magnification of motion has an important effect on the quickness of the coil, and can easily be overdone. In one of the instruments already used, the dimensions of the various parts of the moving system were as follows:—

Moment of inertia of coil = 0·16 grm.-cm.².
Moment of inertia of mirror and saddle = 0·013 „
Magnification ratio $= \frac{r_1}{r_2} = 4{\cdot}0$.

From this the total amount of inertia of the system may be obtained; for using the above figures for the moment of inertia of the coil, and saddle of mirror about their respective axes of suspension, then the total effective moment of inertia of the system around the axes of the coil is—

$$I = 0{\cdot}16 + (4)^2 \times 0{\cdot}013$$
$$= 0{\cdot}16 + 0{\cdot}208.$$

Here it is to be noticed that with the given mirror and coil the mechanical magnification ratio is somewhat too high, for the swing of the system is governed more by the mirror than by the coil. But this does not really matter, for the instrument is intended for low frequency only, and so the moving parts need not be very light.

The damping of the coil is mainly brought about by the currents generated in the aluminium "former" on which the coil is wound, as it moves in the strong field of the magnet. The coil is also damped by the currents induced in it when the circuit is closed, but inasmuch as this damping will be a function of the resistance and other circumstances of the circuit, which it is desired to vary, it is desirable to keep

* An amplitude galvanometer has also been arranged by Mr. Albert Campbell, of the National Physical Laboratory, who has produced a very successful moving-coil modification of Max Wien's vibration needle-galvanometer. The difference between these and the one now described is this—that in the Campbell galvanometer the coil has the least possible damping, like a very quick ballistic instrument, whereas in the galvanometer here described the coil is arranged to be aperiodic. The one is used for null methods, though it also measures frequency, but it cannot be depended on to measure current strength except at constant frequency; whereas the one now described measures current accurately, and frequency not at all. In the one the amplitude of oscillation varies with both the current strength and the frequency, whilst in the other the amplitudes are strictly proportional to the current strength for a considerable range of frequency.

this part of the damping entirely subordinate to that caused by the aluminium frame ; since this, of course, remains constant.

The magnet strength is adjusted until the main damping makes the coil just dead beat. Then if in practice the damping becomes a little greater than this, no harm is done. No inaccuracy is introduced into the measurement so long as the coil has no swing period of its own. A ittle too much damping merely reduces the sensitiveness, that is all.

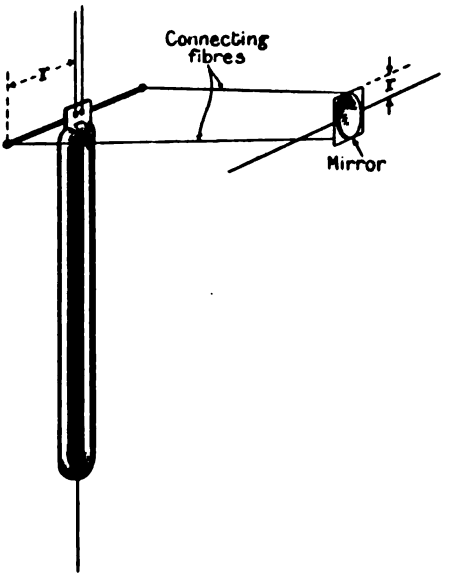


FIG. 3.

The correct magnitude of the damping effect is obtained by observing the disappearance of oscillation when the instrument is joined to a cell in a non-inductive circuit. For this purpose a continuous current is arranged to give a certain scale deflexion. When the deflection just fails to exceed this value, on starting or reversing the current, the system is just aperiodic. With a translucent scale this can be observed by covering the scale up to the division corresponding to maximum deflection of the continuous current ; then on starting the current, the spot of light should just fail to appear beyond the edge of the cover.

Fig. 4 shows the instrument complete.

METHOD OF MEASUREMENT.

The inductance to be measured is connected up in series with the galvanometer and a specially designed sine alternator of small power and known frequency, and the amplitude of the oscillation is observed. The inductance is then removed and a non-inductive resistance placed in its stead, being adjusted so as to produce the same amplitude of oscillation.

The connections are shown in Fig. 5. L R is the impedance to be measured, and R′ is the non-inductive impedance substituted to produce the same oscillation. We have, therefore, the simple relation $R' = \sqrt{(R^2 + p^2 L^2)}$; and since for the majority of the cases in practice R is small compared with p L this gives simply—

$$L = \frac{R'}{p}.$$

The strength of the current involved in the measurement is known from the amplitude of the oscillation, the deflexion being easily reproducible with a known steady current: so that the two measurements, the one for L and the other for the corresponding current, are made simultaneously. The complete specification of the inductances is thus easily and readily obtained.

In order to render the oscillation galvanometer available for a wide range of current values, all one has to do is to shunt it by a non-

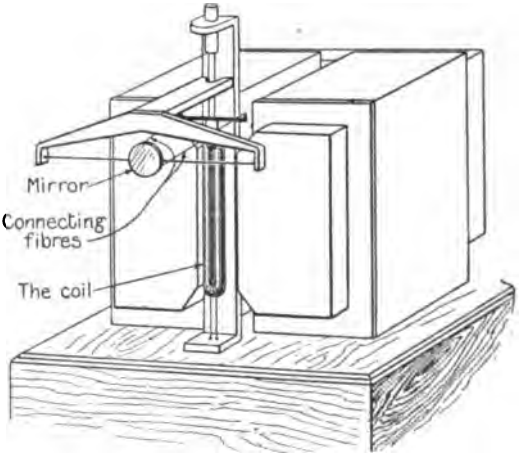


FIG. 4.

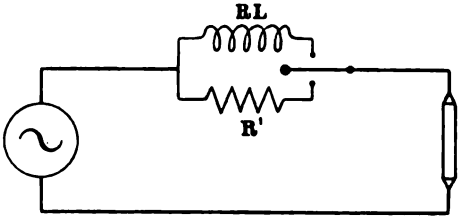


FIG. 5.

inductive resistance. This can be done without appreciable error, since the reactance of the galvanometer is negligible for the range of frequency used in submarine telegraphy.

The speed of the alternator must, of course, be accurately known. The speed is obtained by means of a Judd and Fraser speed indicator, which gives the speed with an error not exceeding 1 per cent. at maximum scale reading.

As an example of the sensibility of the instrument, and the time of swing of the coil, the following figures serve for an unshunted galvanometer intended for moderately weak currents:—

Time of swing of the moving system (without the magnetic field)	$\frac{1}{15}$ second.
Current strength giving 1 mm. oscillation at 1-metre scale distance	4×10^{-6} ampere
Strength of magnetic field (approximately)	3,000 C.G.S.
Magnification ratio	4·0.
Resistance of moving coil	770 ohms.

The above sensitiveness is useful for the measurement of alternating currents of the order of 10^{-4} to 10^{-3} amperes.

For the weaker currents used in the measurements given in Fig. 6 the control had to be reduced. The reduction of control increases the time of swing, but since in cable telegraphy weak currents at the receiving end involve low speeds of signalling, and therefore low current frequencies, there is no objection to increasing the time of swing; and this is always done. The damping should, however, at the same time be lessened; so the process necessitates either an alternative coil or one having an auxiliary device for varying the damping.

With a coil swinging 5 per second and a field of about 3,000 C.G.S. the sensitiveness runs up to a value such that 10^{-6} ampere gives 1 mm. swing at 1 metre scale-distance.

The Behaviour of Iron Inductance under the Action of very Low Magnetic Forces, and Examples of Curves obtained by Means of the Oscillation Galvanometer.

Although under strong magnetising forces the value of L depends largely on the strength of the current, as is well known, and although for this reason an iron-core inductance is a somewhat difficult instrument to use, yet it turns out that when the magnetising forces are weak, the behaviour of iron inductance approaches that of an air-cored inductance, as is shown by readings obtained by means of the oscillation galvanometer.

These are plotted in Fig. 6, which shows how the inductance varies with the current and the magnetising force when the magnetising force is very low. The curve shows that the inductance is practically independent of the current strength for all magnetising forces below 0·04 C.G.S. The range of currents received at the distant end of a submarine cable is such as to give a value $4\pi nC$ (commonly called magnetising force) varying from about 0·001 to 0·02 C.G.S., a range that is more than covered by the curve shown.

The curve shows also that the hysteresis is almost *nil*, since only by a change in the value of L can the hysteresis loop be formed. From this it follows that a sinuously impressed E.M.F. gives also a sinuous current in such an inductance under the conditions named. Hence the iron inductance behaves almost like an air-core inductance, for feeble magnetising forces. This has been found a valuable property of iron inductance coils placed at the end of a submarine cable,

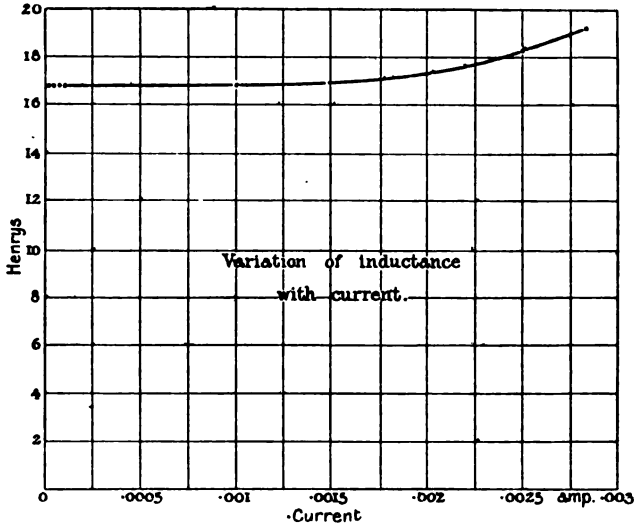


FIG. 6.

[To convert the abscissæ into magnetising force in C.G.S. multiply the current in amperes by 22.]

EQUATION REPRESENTING THE INDUCTANCE VALUES FOR DIFFERENT WIDTHS OF AIR-GAP.

An extremely convenient method of arranging a continuous variation, so as to obtain all possible values of inductance between two given limits, is to arrange the air-gap of the iron circuit so as to be varied by means of a hand screw. Such a specially designed form of inductance, when the magnetising forces are low, is a very satisfactory instrument. Its behaviour is found so uniform that an equation may be obtained which gives, fairly correctly, the values of L throughout a very considerable range of current strength, frequency, and width of air-gap.

Assuming the iron-cored inductance coil to be of the form given in Fig. 7, and made of thoroughly laminated high-quality iron, we devised the following empirical equation to express the self-induction for weak currents under different circumstances :—

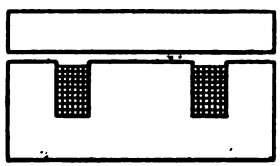


FIG. 7.

$$L = k\, n^{a}\, (G + g)^{-b}.$$

Where n is the number of turns, G the width of the air-gap in millimetres, g a constant depending chiefly on the reluctance of the iron determined experimentally, and a, b, and k other constants depending mainly on the design of the instrument.

The equation holds good for low magnetising forces and for a moderate change in frequency. If the frequency change and the

magnetising force be either or both of them greatly augmented, the equation becomes complicated.

For an instrument of the form given in Fig. 7 the values of the constants were as follows—

$$a = 1{\cdot}99$$
$$b = 0{\cdot}47$$
$$g = 0{\cdot}1$$
$$k = 18{\cdot}0.$$

Note that G is to be expressed in mm. not cm.

Fig. 8 is a curve showing how the inductance varies with the

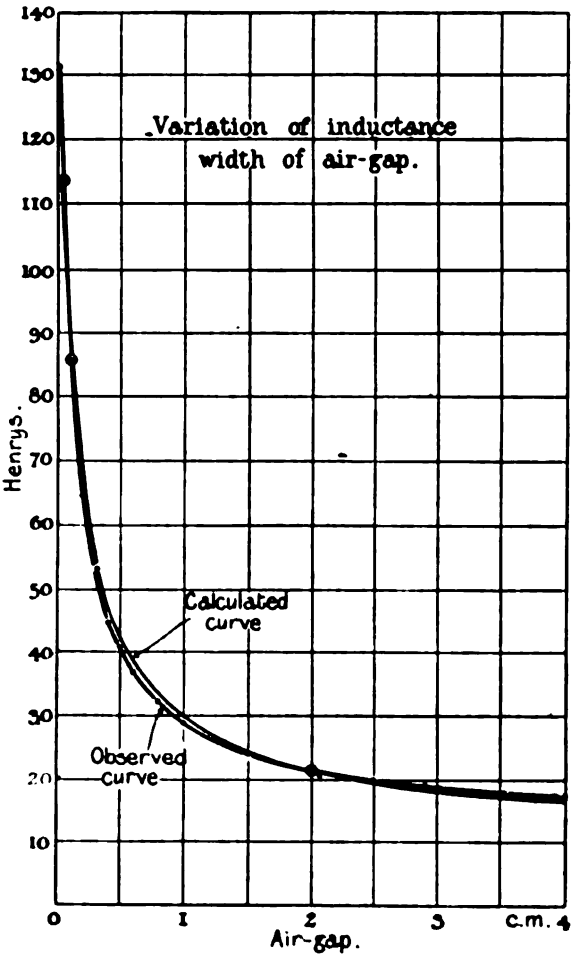


FIG. 8. – Showing how the Inductance depends upon Width of Air-gap, and how nearly the above Empirical Expression for L agrees with Observation.

thickness of the air-gap; both by calculation from this formula and by direct observation. It is to be noted how closely they agree, up to so narrow an air-gap that the inductance becomes 114 henries. Though if the air-gap is reduced below half a millimetre discrepancy begins to set in.

Distribution of Magnetism in the Cross-section of the Iron Core.

A rough observation was made with the view of determining how the density of the magnetic induction varied from point to point in the

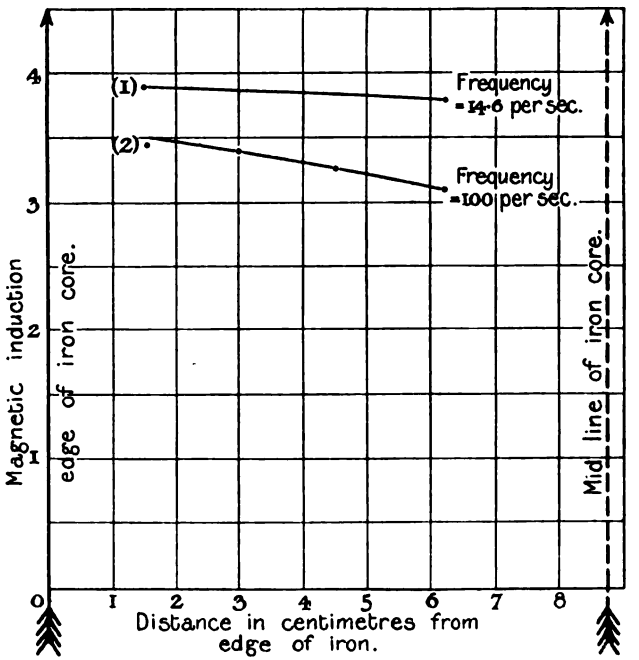


Fig. 9.—Distribution of Magnetic Induction in Cross-section of Iron Core.

• cross-section of the iron core of the inductance when the frequency of the magnetising current was varied.

In an iron magnetic circuit whose cross-section was about 220 sq. cm. a small air-gap was arranged—the gap being at right angles to the length of the circuit and to the lines of induction.

The relative intensity at various points in the plane of the gap was measured by means of an exploring coil connected to the oscillation galvanometer, while the alternating current producing the induction flowed through the main coils of the inductance. The amplitude of the galvanometer oscillation was thus a measure of the intensity of induction,

With a steady magnetising force the distribution of induction is uniform except at the edges where the fringe effect is observed. But with a varying magnetising force, such as that given by a sinuous current, there is apparently a screening effect, or something analogous to screening, which prevents the interior portion attaining the full value of magnetisation appropriate to the impressed magnetising force.

Fig. 9 gives two curves showing the magnetic induction for a frequency of 100 per second, and for a frequency of 14·6 per second, in the interior of the air-gap at different distances from the centre.

By extra polation it is seen that the drop in the value of the magnetic induction between the edge of the iron core and its centre is about 3 per cent. for the lower frequency and about 22 per cent. for the higher frequency.

This explains in part the decreasing value of L of such an instrument as the frequency is raised.

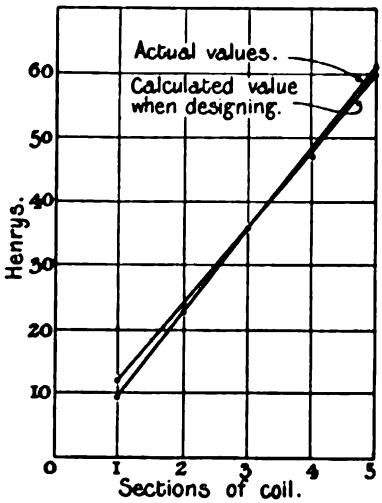


FIG. 10.—Showing Agreement between Theory and Practice.

Inductances of another form have been designed with the figures given above as the basis. These were to give inductance values for the different sections increasing in arithmetical order from 12 to 60 henries for a constant air-gap of 0·1 cm. The curves, Fig. 10, show the predicted values and the actual values given by the instrument after it was built.

THE PERMEABILITY OF THE MAGNETIC CIRCUIT FOR VERY LOW MAGNETIC FORCES.

The mean value of the permeability may be roughly estimated from the inductance and the geometrical dimensions of the instrument.

The flux $N = \frac{4\pi n C A \mu'}{l}$, where $4\pi n C$ is the magnetising force, A the cross-sectional area of the iron, and l the mean length of the magnetic path.

Therefore the mean permeability $\mu' = \frac{L l}{4\pi n^2 A}$.

For a magnetic circuit containing four closely fitting planed and polished surfaces in series with each other, and all at right angles to the lines of induction, this gives the value of μ' as 228. This magnetic

circuit is made of Stalloy iron plates 0·014 in. thick and closely packed. The magnetising force being 0·0003 C.G.S. per centimetre, and the alternating-current strength 8×10^{-6} C.G.S. The form of the magnetic circuit of this inductance is approximately that given in Fig. 7.

Ratio of the Inductances of a Coil With and Without Iron.

Calculating the inductance L′ of a coil alone, and measuring the total inductance L of the coil with iron, the instrument under consideration in the previous paragraph gives the value of the inductance of the iron-cored coil as 44 times that of the ironless one, or—

$$\frac{L}{L'} = 44 = k.$$

The Value of μ' Again.

A superior limit to the value of μ' may be obtained from the value of k. Assuming the coil to be completely surrounded by iron to a great depth in space, instead of being simply linked with an iron rectangle as in Fig. 7, the reluctance of the exterior magnetic circuit would become small in comparison with that of the interior. If the exterior reluctance were negligible, the total reluctance would be reduced to about $\frac{1}{6}$th of that which gave $k = 44$ above, since the iron part of the mean magnetic circuit is approximately $\frac{1}{6}$th of the whole length. This reasoning would give—

$$\mu' = 6\ k = 264.$$

The value of μ' as actually measured was 228.

Results.

Beside the method of measurement here described the following results have been obtained :—

1. That measurements based on a determination of square root of mean square would serve fairly well for low magnetising forces.
2. That the inductance of an iron-cored coil is nearly independent of frequency for all frequencies up to about 20 per second, when the magnetising force does not exceed 0·04 C.G.S.
3. That the inductance of a nearly closed magnetic circuit is a definite and dependable function of the width of the air-gap for moderate currents and frequencies.

ORIGINAL COMMUNICATION.

MAGNETIC RELUCTANCE OF JOINTS IN TRANSFORMER IRON.

By Dr. H. BOHLE, Cape Town, Member.

(*Received April 27, 1908.*)

For the determination of the no-load currents of transformers a knowledge of the magnetic reluctance of the joints in the iron core is necessary. The usual practice consists in assuming that each joint is equivalent to a film of air 0·005 cm. long, this being the mean of a number of values given by Professor Ewing in his well-known treatise, "Magnetic Induction in Iron and Other Metals," on pages 285–291. Unfortunately, these figures were obtained from tests on solid rods, whereas for transformers laminated cores can only be employed. Moreover, the tests were made with butt joints alone, and data for overlapping joints are not available, at least as far as the author is aware.

In transformer design, some assume that cores with overlapping joints are equivalent to jointless frames, while others consider overlapping joints no better than butt joints.

The object of the present paper is to determine how far Professor Ewing's data hold for laminated cores, and the relative merit of butt and overlapping joints.

Description of Apparatus.—Two magnetic squares were built up, one jointless, the other consisting of stampings capable of being placed together so as to form abutting or overlapping joints, without altering the mean length of the magnetic path. The number of joints in each case was four. To make the flux distribution as uniform as possible over the whole cross-section, the width of a stamping was made less than one-tenth of a side of the square. The exciting winding of 460 turns was placed uniformly along the whole circumference, in order to reduce magnetic leakage to a minimum. The quantity of iron employed was 10 kgs. per magnetic square. For testing direct current was employed, which is permissible, since the magnetisations due to direct and alternate currents differ little, according to the investigations by Gumlich and Rose.

Although the stampings of both frames were supposed to be obtained from the same bulk of material, a direct comparison was impossible, because permeabilities differ often even within a single sheet. In fact, it was found—also shown in the accompanying figures

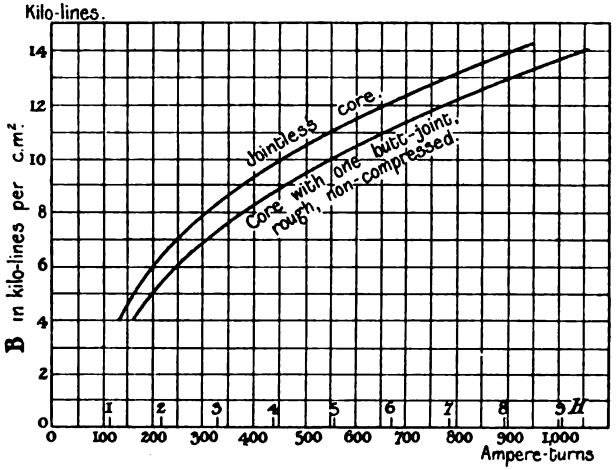


FIG. 1.

—that the material for the jointed core was a great deal superior to that for the jointless core. This difficulty was overcome by testing—after demagnetisation—the first frame with the core in one piece, and

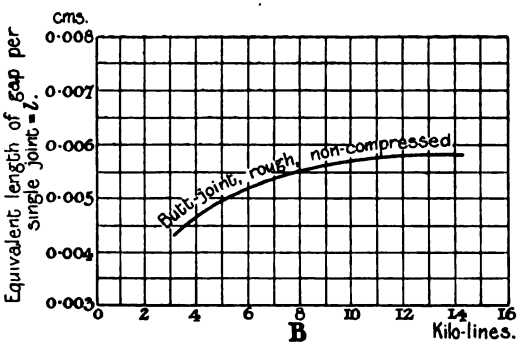


FIG. 2.

again after it had been provided with a butt joint. The results of these two tests are shown in Fig. 1, and the equivalent length of air-gaps in Fig. 2. The abutting surfaces were carefully brought together, but without compression.

The second frame was next used, built up with four butt joints,

carefully made but neither compressed beyond what was due to the weights of the cores, nor machined. Previous to each test the iron was demagnetised as far as possible. The test was then repeated by placing the joints under compression by means of suitable clamps. The actual compressive stress was not measured, but was of a nature corresponding as far as possible to actual transformer practice. The

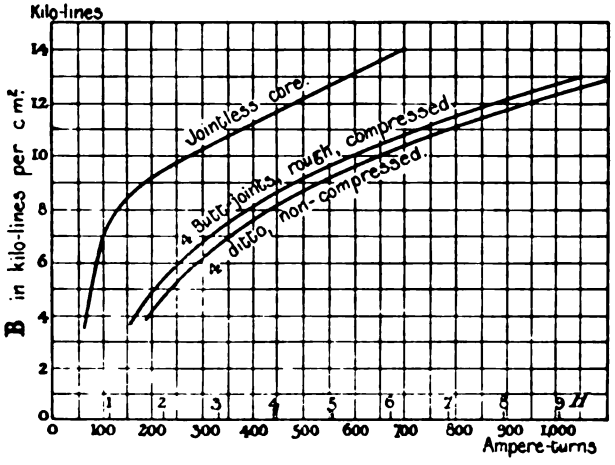


FIG. 3.

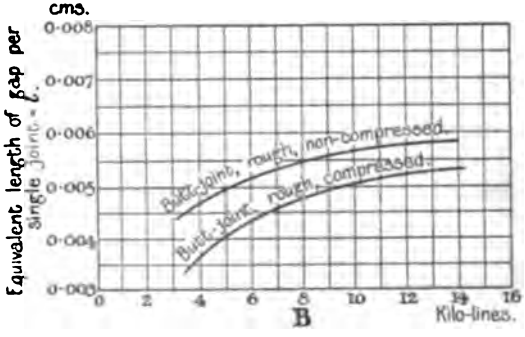


FIG. 4.

results of the tests are illustrated in Figs. 3 and 4, together with the magnetisation curve corresponding to a jointless core, which could now be plotted with the aid of Fig. 1. It will be noticed that the iron of the jointed frame is superior to that of the jointless core.

Frame No. 2 was then taken to pieces, and this time built up with overlapping joints, demagnetised and tested as before. The results are shown in Figs. 5 and 6.

The four cores of the same frame were then once more arranged with butt joints, which were this time carefully machined and tested, (1) non-compressed, (2) compressed, obtaining the results shown in Figs. 7 and 8.

In order to be able to compare the relative merits of the different types of joints, the results have been plotted in the following table :—

TABLE.

Flux Density.	Equivalent Length of Single Air-gap in Centimetres.				
Lines per Square Centimetre.	Butt Joint, Rough, Non-compressed.	Butt Joint, Rough, Compressed.	Overlapping Joint.	Butt Joint, Machined, Non-compressed.	Butt Joint, Machined, Compressed.
4,000	0·00470	0·00370	0·00165	0·00470	0·00290
5,000	0·00495	0·00405	0·00205	0·00495	0·00320
6,000	0·00520	0·00430	0·00240	0·00520	0·00335
7,000	0·00535	0·00460	0·00270	0·00530	0·00355
8,000	0·00545	0·00475	0·00300	0·00540	0·00370
9,000	0·00555	0·00490	0·00320	0·00547	0·00380
10,000	0·00560	0·00505	0·00330	0·00550	0·00395
11,000	0·00570	0·00515	0·00340	0·00555	0·00410
12,000	0·00575	0·00520	0·00350	0·00560	0·00425
13,000	0·00580	0·00530	0·00360	0·00565	0·00430
14,000	0·00585	—	—	—	—

In analysing the results of this table we find that a machined butt joint when not compressed is no better than a rough one. In both cases is the length of the gap reduced considerably when compression is applied, especially in machined joints, which are almost as good as overlapping joints. The reluctance of the latter, although lower than that of the ordinary butt joint, is by no means a negligible quantity, especially for high flux densities. The reluctance of these joints is due to the fact that the flux bends out from one sheet to another, whereby the flux is somewhat contracted, this being equivalent to an increase in the length of the gap between the sheets. As the contraction increases with the flux density, the rising of the curve in Fig. 6 is natural. Also the insulation of the sheets (those used in the test were coated with varnish) augments somewhat the length of the gap.

It would appear from these tests that a mean value of 0·005 cm. per single gap would meet the case for all butt joints. Experience has, however, shown that this is hardly correct. In the above tests the sheets were assembled with the greatest care, so that the abutting ends were perfectly even; but such accuracy cannot be bestowed on work done in the factory. In all cases it will be safer to use values 50 or even 100 per cent. higher than those given in the table, according to workmanship.

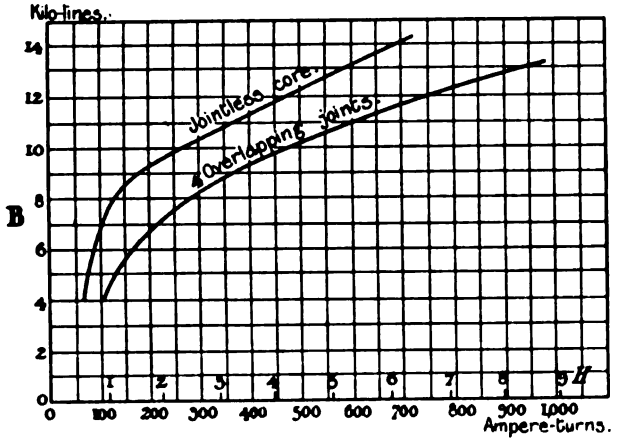


FIG. 5.

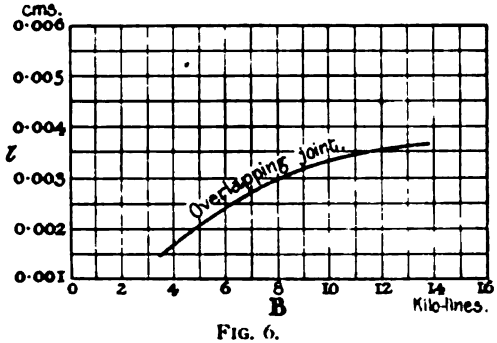


FIG. 6.

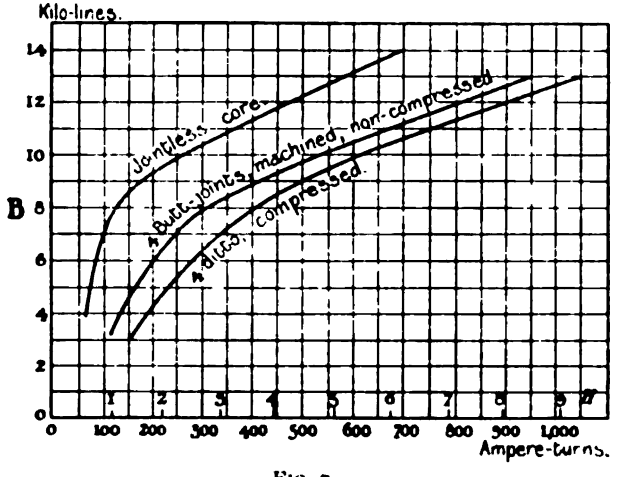


FIG. 7.

As regards overlapping joints, a gap length of 0·004 cm. will in most cases give results on the safe side, this being somewhat larger than the mean value in the table, taking into account uneven insulation of the stampings.

When cores are so placed together that the stampings cross one another, it is essential that a thin sheet of insulating material is inserted to prevent the production of eddy currents near the joint. The thickness of the insulation should then be added to the figures given in the table.

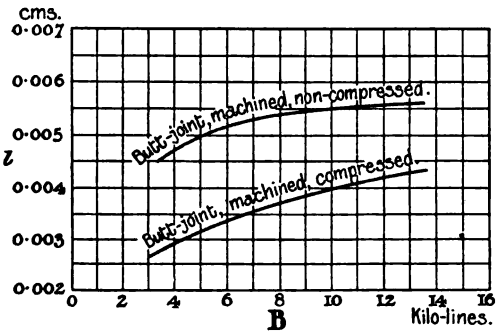


FIG. 8.

As regards the setting up of eddy currents, overlapping joints are little better than butt joints, and the type of joint applied will, therefore, depend chiefly upon the class of work the transformer is intended to do. For lighting transformers a small no-load current is of great advantage to reduce the wattless currents. For power transformers which are usually disconnected when the power is no longer required, and which are more fully loaded, the wattless currents are of no importance, and butt joints are no disadvantage. As regards the manufacturing cost, there is little to choose between the joints except in the case of large transformers, where butt joints are somewhat cheaper.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 41. 1908. No. 192.

Proceedings of the Four Hundred and Seventy-eighth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Royal Society of Arts, John Street, Adelphi, on Thursday evening, May 7, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on April 30th, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members :—

Theo. E. Thomas. | Charles Wyatt.

From the class of Students to that of Associate Members :—

John Butcher. | R. A. Sheldon.

Messrs. C. C. Paterson and F. J. Gerrard were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

Selig Kenneth Broadfoot.
Walter Golding.
Charles William Inggs.
Walter Elderton Kidner.
Maxwell B. Logan.
Arthur R. Macdonald.
Dr. Mario De Andrade Ramos.
Herbert Robertson.
Lewis Anderson Smart.

As Associate.

Thomas Pearson.

As Students.

Reginald Gilray Barton.
Harry Norman Cunliffe.
Percy Furness.
Alan Edward D. Kennard.
David John Leacock.
Frank Parkinson.
Alexander Schmidt.
William Arthur Stephens.

The following students were omitted from the list of April 2, 1908:—

William Anthony A. Burgess.
George William Burley.
Hugh Ching.
James Claughton.
James Davies.
Arthur Edward H. Dinham-Peren.
Stanley Dudman.
Kenneth Newton Eckhard.
Aneurin Caradoc Evans.
William Arthur Fletcher.
William Basil Garrett.
Birendra Chandra Gupta.
Leslie Gordon Harris.
Cedric Dudley Hayhurst.
Cecil Hugh Hayward.
Harold Cecil Heath.
Leonard Robert Hickman.
Arthur Reginald Hinde.
Douglas W. J. Janes.
William Geden Johnson.
Geoffrey Harcourt Landon.
Frederic Charles Lunnon.
George Meyer Meyer.
Percy Nutter.
Donald Ashmore Pearson.
Graham Francis H. Satow.
Ernest Saunders White.
Arnold Morley Willis.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Blackie & Sons, Ltd., the Engineering Standards Committee, E. Guarini, E. P. Hyde, R. B. Matthews, the Allgemeine Elektrizitäts Gesellschaft; and to the *Building Fund* from J. H. Garratt and A. Wright, to whom the thanks of the Institution were duly accorded.

The following paper was read and discussed :—

THE MANUFACTURE OF ELECTRICAL CONDENSERS.

By G. F. MANSBRIDGE, Member.

(*Paper received January 8, and read in London on May 7, 1908.*)

Although electrical condensers are among the oldest devices in the art of applied electricity, it is only within the last few years that the demand for them has assumed any degree of commercial importance. Until about 1898 practically the whole of the supplies were for telegraph work, but since then the situation has been entirely changed by the great development of the telephone service of the world, and particularly of the common-battery system, in which condensers play a modest but important *rôle*. The magnitude of the present demand may be gauged from the fact that the aggregate output of condensers in Europe and America during 1907 is estimated at the once-inconceivable capacity of 5 farads.

With manufacture established on this scale, economy in production is imperative, and the skilled hand of the 'nineties, who laboriously assembled or "built" his 1 or 2 microfarads per day, has given place to the machine hand who, with less physical distress, readily turns out one hundred times that quantity per diem. As a result the manufacturing costs have been so greatly reduced that condensers equal in quality to those produced ten years ago can now be purchased at approximately one-tenth the price. This reduction in cost has brought about a yet further increase in the demand, since it now pays to employ condensers for many services from which they were previously shut out by their high cost. Consequent, no doubt, upon the newness of the industry, very little seems to have been published in the way of precise physical, electrical, or manufacturing data, and the present paper is an attempt to deal with some of the technical points which seem to be of the most importance in the manufacture and use of condensers.

Throughout the paper the subject has been looked at chiefly from the point of view of the practician ; the numerical data quoted must therefore be considered, not as figures obtained in a laboratory, but as representing the carefully digested results of workshop tests made in the ordinary course on large batches of condensers. These tests, though made with reasonable care, may not be of the high order of accuracy obtainable with tests of isolated specimens taken under laboratory conditions, but it is thought that their accuracy is sufficiently

close for all ordinary purposes, and that they will be of practical value as representing the average of a very large number of results obtained under commercial conditions. The author has, moreover, no respect for five-figure results worked out on two-figure galvanometer deflections.

Many of the data are gleaned from the records of the Post Office factory at Mount Pleasant, Clerkenwell, London, E.C., and for permission to publish these the author has to acknowledge his indebtedness to Mr. J. W. Willmot, I.S.O., the Controller of the Factories' Department of the Post Office.

For convenience of description, the various types of condensers are considered separately. They fall naturally into four chief classes namely—

I. Mica.
II. Glass.
III. Paper or other fibrous material impregnated with wax, resin, oil, etc.
IV. Electrolytic cells.

I. *Mica Condensers.*—On account of the very high cost of mica sheet suitable for the work, condensers of this form are but little used.

Mica condensers, when well made, retain their capacity and insulation better than those made of paper, and they have also a higher dielectric strength for the same thickness, but the cost per microfarad is approximately ten times greater than that of paper condensers. Fortunately, the inductive capacity of mica is high (about twice that of paraffined paper), or the labour cost would be excessive, since the size of the sheets is limited to about 4 in. by 3 in., the cost of larger sheets of uniform thickness being prohibitive. A good working thickness is 0·0015 to 0·002 in., and if the material is carefully selected there is no necessity, for ordinary purposes, to use more than one sheet between consecutive foils. For purposes where mechanical strength in the condenser plate itself is of special advantage mica is very satisfactory, and for standards it is unrivalled. In standards the chief desiderata are:—

(1) Constant capacity with efflux of time.
(2) Constant capacity with varying temperature.
(3) High insulation and low absorption.

To obtain (1) it is necessary that the mica and tinfoil sheets be perfectly flat and free from inequalities, so that they will build up under pressure into a solid mass without flexure or mechanical strain; it is also necessary that in assembling the sheets all air-bubbles be excluded.

To obtain (2) advantage is taken of the fact discovered by Dr. Alexander Muirhead* that the mica sheets have a positive temperature

* U.K. Patent 15337, 1891, A. Muirhead.

coefficient if coated with shellac, and a negative temperature coefficient if coated with paraffin. By building a condenser in two sections, one treated with shellac and one with paraffin wax, the variation of capacity within ordinary limits of temperature can thus be brought practically to vanishing-point.

To obtain (3) it is necessary to use only selected sheets of the finest clear "ruby" mica, which must be uniform in thickness throughout the sheet, and free from cracks, veins, or flaws; spotted or "speckled" mica is useless for the purpose.* The shellac employed should be the finest button lac dissolved in absolute alcohol and carefully strained until perfectly free from suspended matter. The building up or assembling of the sheets of foil and mica may conveniently be done on a "hot plate," the greatest care being taken to exclude air-bubbles, grit, or excess of paraffin or shellac. The desiccation should be slow but thorough, and the temperature should not exceed 212° Fahr. The finished condenser should be carefully and not excessively pressed, and should be allowed to cool under pressure in the ordinary way.

II. *Glass Condensers.*—A few years ago the Leyden jar would not have called for comment in a "practical" paper, but the requirements of wireless telegraphy and X-ray work have latterly increased the importance of apparatus of this character, and there is now quite an appreciable trade in glass jars for this specific purpose. As is well known to wireless workers, Leyden jars, like other condensers, are prone to fail in use if at any point there is imperfect contact between the conductor and the dielectric, and to avoid this difficulty the best plan is to silverplate the glass. This may be done by precipitating metallic silver on to the glass in the form of a bright continuous film by the well-known method employed for silvering galvanometer mirrors, etc. The solution generally used is nitrate of silver which has been treated with ammonia until the precipitate first formed has been completely re-dissolved. The surface of the glass must be cleaned with the most scrupulous care before plating is attempted, or an imperfect coating will result. The silver coating should then be mechanically strengthened by a protecting layer of varnish, or it may be over-plated with copper.

An important development of this silver-plated Leyden jar is to be found in the Moscicki high-tension condenser recently placed on the market. A brief description of this condenser has already been made public, but it is thought that the apparatus is of sufficient interest to warrant detailed reference, and by the courtesy of Messrs. Isenthal & Co., of Mortimer Street, London, the author is able to exhibit a condenser of this form in a manner which will permit of the construction being readily seen. In the author's opinion this condenser represents the most satisfactory and practical high-tension condenser for commercial work which has been introduced up to the present.

* An interesting memorandum on mica has recently been published by the United States Department of the Interior.

The failures of previous high-tension condensers were due to imperfect adaptation of the material to the requirements and to the inherent weakness or instability of the dielectric, and, as is well known, the working life of such condensers was invariably short. In the Moscicki condenser great technical skill has been shown in adapting the material so as best to meet the onerous conditions. An imperishable and highly stable material, glass, is used for the dielectric, a most intimate and complete contact is made between the conductor and the dielectric by chemical deposition of silver, excessive strains are avoided at the point of high dielectric stress (the edges) by suitably thickening the dielectric at this point, and the effects of local heating are minimised by water-cooling. The failures of high-tension condensers of other types have no doubt engendered a certain feeling of distrust in the minds of many station engineers, and it may be that this suspicion will take some time to eradicate. In view, however, of the large number of stations working with a power factor ranging about 0·75, and of the advantages to be gained by improving this power factor, the author would suggest that the question of installing a battery of modern glass condensers at such stations is worthy of more than passing consideration.

III. *Condensers with Paper or other Fibrous Dielectrics.*—Although this form of condenser has been employed for many years, there have been but few important changes in the process of manufacture until lately. The standard practice up to the last decade was to use separate sheets of tissue paper and separate sheets of thin metallic foil, and the method employed was to dry the paper by heat, then to transfer it to a bath of hot paraffin wax, and after due soaking to build up the condenser on a "hot plate," the paper being taken sheet by sheet from the bath of hot wax. At least two sheets of paper were used between consecutive foils, the alternate foils being bunched into two books in the well-known way. The paper used was of fine quality, giving only a minute percentage of ash on incineration, being free from grit, holes, specks, etc., and being neutral in chemical reaction. A good working thickness was 0·001 in. The metal foil was usually of tin, the thickness being about 0·0003 in.

Obviously this method of building condenser plates was slow, tedious, and expensive, and it had the further disadvantage that as the workmen who handled the material were exposed to a high temperature, the risk of contamination of the wax by emanations from the body was great; indeed, the difficulty was such a serious one that the manufacture of satisfactory condensers in very hot weather was practically impossible, and in London it often became necessary, on this account, to cease manufacture during the summer months. Even in cooler weather it was necessary to select workmen who were not prone to perspire freely, as only such men could be depended upon to produce condensers with satisfactory and permanent insulation. In consequence of this difficulty, the author found it of advantage to build up the condenser plates "dry" in a separate room and to

desiccate and impregnate the condensers as a subsequent operation. By this arrangement practically all the handling was done under more favourable conditions in a cool shop, and the electrical results obtained were more satisfactory than under the old system, and at the same time the cost of manufacture was considerably reduced. The slow process of assembling the sheets one by one and of handling about 250 separate pieces to make up a 1-microfarad plate had, however, still to be reckoned with, and the percentage of failures through short circuit or low insulation was considerable, so that the labour cost remained an important factor.

The next step was in the direction of bringing down this high labour cost by reducing the number of pieces to be handled. The method adopted was to wind up into the form of a roll long strips of metal foil, two strips of paper being interposed between each foil—that is, six strips in all. This method, which was introduced to the Post Office by Sir John Gavey in 1899, had, however, difficulties of its own. Pure tin foil of the requisite thinness could not at that time be obtained in strips longer than a few feet, and the alternatives were: (1) to feed between the rolls of paper a series of strips of pure tin foil some 4 ft. long, each strip overlapping its predecessor by an inch or two so as to maintain continuity; or (2) to use an alloy of lead and tin which could be obtained in continuous lengths. The former was an awkward and unmechanical arrangement, and the latter had the disadvantage of producing a heavy and bulky condenser. Both methods also involved a considerable proportion—rarely less than 10 or 15 per cent.—of short circuits in the finished plates brought about by grit in the foil or by defects in the paper. In endeavouring to overcome these difficulties, the author hit upon the idea of using metallised or "foiled" paper of the same character as that sometimes employed for wrapping up packages of tea, etc. Experiments showed that commercial "tin-foiled paper" as then made was not sufficiently reliable as an electrical conductor for the purpose; indeed, many samples, although having apparently an excellent metallic surface, were found to be almost as devoid of conductivity as paper itself. Microscopic examination revealed that this want of conductivity was chiefly due to the tin being distributed, not as a continuous film over the surface of the paper, but in small isolated patches, the breaks between the contiguous patches being due to small fibres of the paper standing above the average level. Further, it was found that even in those samples which gave fair conductivity in the plain sheet very little creasing of the paper sufficed to destroy the continuity. The matter was, however, considered sufficiently promising to warrant careful investigation, and the difficulties in the way of producing a thoroughly reliable conducting surface on such paper were found to be surmountable.*

For assistance in carrying this part of the work to a successful issue, the author desires to express his indebtedness to Messrs. Olive

* U.K. Patent 19451, 1900, G. F. Mansbridge.

& Partington, Ltd., of Upper Thames Street, London, who gave the matter considerable technical attention at their works and who were the first to produce foiled paper for electrical purposes on a commercial scale. As soon as supplies of good electrical foiled paper became available the manufacture of condensers on this principle was taken up by the Post Office, and subsequently by various commercial firms, under licence from the patentee.

The process of preparing this foiled paper is fairly well known in the paper-making trade, but as the matter will probably not be so familiar to members of this Institution, a brief description may be of interest.

As is well known, metallic tin may be thrown down from its solution either chemically or electrically in the form of an impalpable powder, and the preparation of the finely divided metal is the first process. The ingot tin—previously granulated or "feathered"—is dissolved in nitrohydrochloric acid, and after all scum and insoluble matter have been removed, the solution is diluted and the tin is carefully precipitated by metallic zinc, or by the action of a weak electric current. For the best results the most minute subdivision of the tin is essential, since only the thinnest layer of metal is desired, and unless this layer is uniform, metal will be wasted or imperfect continuity will result. After precipitation the powder is repeatedly washed to free it from all traces of acid, and is sifted through sieves of the most minute mesh so as to eliminate all large particles of tin or any grit with which it may have become contaminated. A suitable adhesive such as size is added, and the tin mud is then passed to the coating machines. These are provided with mechanical stirrers to prevent the metal settling, and with rotating brushes and spreaders to distribute the metal evenly over the surface of the paper as the latter passes through the machine. In some machines the paper is passed over heated cylinders so as to dry the coated surface quickly, but as this is liable to reduce the efficiency of the adhesive it is preferable that paper for electrical purposes should be dried more slowly—for instance, by exposure to currents of warm air. The dried paper then presents a dull grey appearance, and microscopic examination shows that the surface is covered by a magma of minute crystalline particles forming a layer of appreciable depth. The paper then passes to the burnishing rolls, which consist of heated heavy steel calenders or friction rollers between which the paper is fed. These friction rollers compress the dull magma of tin powder into a coherent thin film having the lustre of the polished metal. During this process any comparatively large crystals of tin or particles of grit which may have escaped untrapped will be driven partly or wholly through the paper, but the effect of this is eliminated by the subsequent electrical treatment, as described later on. The paper is now passed to the slitting machines, where it is trimmed and cut to any desired width.

It is interesting to note that prior to the calendering process referred to, the film of tin powder is non-conducting, the conductivity

being produced by the action of the steel burnishing cylinders, which so consolidate the coating as to bring the particles into intimate contact each with its neighbour. Perfect contact between every particle of tin and its immediate neighbours can hardly be expected, but in view of the entire want of conductivity before calendering, it is perhaps surprising that in properly calendered foiled paper, with a fairly heavy coating, the conductivity of the coating may be as much as 50 per cent. of that of a continuous strip of pure tin of equivalent weight. On the foiled paper as usually made for condensers, the quantity of tin averages 25 grains to the square foot, and the conductivity is about 25 per cent. of that of pure tin, the resistance of a strip 1 ft. wide averaging 0·3 ohm per foot run, that is, 0·3 ohm per square foot or per square metre. This density of coating gives a surface of 280 sq. ft. to the pound of tin, or say, 57 sq. metres per kilogramme of tin. The average thickness of the tin film is therefore as nearly as possible 0·0001 of an inch, or say, 0·0025 millimetre. Seeing that the material is semi-transparent, the current-carrying capacity of this film is surprisingly high, the fusing current in air being rather more than 1 ampere per inch of width for the standard coating of 25 grains per square foot; this is assuming that the paper has not been creased. Bending the paper round even a very small radius does not affect the continuity, but if the paper be very closely folded back on itself so as to put the film sharply in tension or compression, a certain amount of disintegration follows, and the fusing current is correspondingly lower. By using a greater density of coating, say, 40 grains per square foot, the effect of creasing is greatly diminished, but there is no necessity for this higher density in condenser work, since the creases in the rolled condenser even at the centre of the roll are not very sharp.

Continuous reels of electrically-conducting foiled paper being available, the manufacture of a condenser is a very rapid and simple operation, since all that is necessary is to roll up together two strips of foiled paper, interleaved with two strips of plain paper, the number of turns being dependent on the capacity required.

The foiled papers may be placed with their metallic sides facing each other, but separated by the two plain papers, in which case the two body papers form the dielectric on the opposite side, or, alternatively, the papers may be arranged so that the dielectric on each side is made up of one body paper and one plain paper. The latter plan is preferable, as it gives a more even distribution of the dielectric strain. Interleaving paper is invariably used for telegraph or telephone condensers, since the insulation otherwise obtainable is but a few megohms. The machine usually employed for the rolling operation accommodates two reels of plain and two reels of foiled paper, and is provided with a set of interchangeable winding mandrels of various diameters. The winding of the strips on to the mandrel is usually done by hand if the number of turns per condenser is small, but in some instances more than a hundred turns have to be wound on, and the mandrel may then be power driven with advantage, but in this case a mechanical

counter becomes essential. The placing of the strips in position and the starting must be done by hand, and this also applies to the insertion of the connecting lugs, which should be strips of annealed copper foil, about 0·001 in. thick and $\frac{3}{8}$ or $\frac{1}{2}$ in. wide. These strips are simply slipped into place between the foiled surface and the interleaving paper, and are so light that they readily retain their position; they should make contact with the foiled surface over practically its full width and should protrude about 1 in., so as to serve subsequently as a soldering point for the wire connection. The two lugs should be placed at the middle of the foiled strips rather than at the beginning or end, so as to avoid interposing any appreciable resistance into the condenser circuit. This plan has the additional advantage that thereby the innermost layers, which possibly may have been rather sharply creased, are not called upon to transmit any considerable current on charge or discharge, as would be the case if the lugs were placed at the inner end of the roll.

The necessity for having mandrels of different diameters arises from the fact that variously shaped condensers are demanded; obviously plates of any desired capacity can be made on any one mandrel by merely varying the number of turns. From first principles it would be expected that the capacity would be directly proportional to the area of the electrodes, but in practice it is found that, within limits, plates of high capacity require appreciably less area per microfarad than those of low capacity. This is particularly the case where the thickness of the plate is small in comparison with its length and breadth. There is therefore a saving in material as well as in labour by building the plates in as large units as possible. Further, it is found that plates built with narrow foiled paper require less material per microfarad than those built with wide paper, the treatment and material being otherwise identical throughout. This effect is doubtless due to the wider paper offering greater facilities for trapping the paraffin instead of allowing it to be expressed. The two effects taken together indicate that a condenser in the form of a cube would require less material than one in any other shape. The cube is, however, not the most suitable shape for manufacture, and as the conditions of service are often such as to demand the adoption of thin, flat plates, the usual compromise has resulted. The standard sizes adopted by the Post Office are shown in the specifications included in the Appendix. The capacity most in demand for telephone work is 2 microfarads, and as plates of this size form a convenient manufacturing unit, they are usually taken as the basis on which to frame standard data for manufacturing purposes. Condensers of larger capacity are almost invariably built up by assembling standard units, rather than by direct manufacture in large plates. The usual sizes of paper at present in use are: for interleaving paper, $7\frac{1}{8}$ or 4 in. wide by $\frac{1}{4}$ mil thick, giving about 400 sq. ft. to the pound; for foiled paper, $6\frac{3}{8}$ or $3\frac{1}{4}$ in. wide by $1\frac{1}{4}$ mils thick, giving 100 sq. ft. of conducting surface to the pound, and consisting of 35 per cent. tin and 65 per cent. paper.

At one time an unfoiled margin was left on each side of the foiled strip, but since the introduction of the "breakdown process" subsequently referred to, this has been found unnecessary. The substance of the paper is gauged on a ten-fold thickness by means of the usual screw micrometer, as specially made with large contact surfaces for paper gauging. With 1½-mil foiled paper and ½-mil interleaving paper, the area required for a 2-microfarad plate is about 12½ sq. ft. for each electrode. The volume of the plate after waxing and pressing is approximately 7½ cub. in., and the weight 7 oz. The insulation between the electrodes, taken at 60° Fahr. with 400 volts after one minute's electrification, usually lies between 1,000 and 2,000 megohms per microfarad.* Any lower insulation than 1,000 megohms per microfarad is an indication of imperfect desiccation, excessive pressure, or faulty material.

It should be noted that the specific insulation (resistivity) of foiled paper is lower than that of plain paper, the difference being due chiefly to the fact that the former is heavily sized. It is, however, only for special purposes that condensers of extremely high insulation are demanded. In such cases, by using the utmost care and material of the very highest quality, it is possible to obtain an insulation of nearly 20,000 megohms per microfarad (400 volts, 60° Fahr., 60 seconds). Such condensers are invariably built up of sheets rather than by the rolling process, since it is necessary to use only perfect sheets, and the rolls of paper cannot readily be examined; under these conditions metallic foil may be used in preference to foiled paper. Three sheets of paper are usually interleaved between consecutive foils. The obvious, but often overlooked, fact may here be commented upon that to increase the number of interleaving papers, while increasing the actual insulation of the plate, does not increase the "megohms per microfarad," since the capacity falls in proportion to the rise of insulation, provided, of course, that there is no abnormal leakage through definite faults.

For certain purposes, such as absorbing the spark across the break of sparking coils, leaky condensers, that is, condensers with specially low insulation, are of advantage, since the high-resistance shunt afforded by the low insulation across the break materially assists in suppressing the primary spark and in thereby lessening the pitting of the contacts. The low insulation necessary may conveniently be obtained by rolling up foiled paper without any interleaving paper, the plate being in other respects treated in the ordinary way. The insulation obtainable will depend partly on the thickness of the foiled paper and partly on the intensity of pressing, but will usually be of the order of a megohm. An important detail in the manufacture of condensers for spark suppression is that there must be no appreciable resistance in the condenser circuit, that is, in the electrodes or thin connections. The

* The expression "megohms per microfarad," though incorrect, is so generally employed that the custom has been followed throughout this paper; the phrase should, however, invariably be interpreted as "megohm-microfarads."

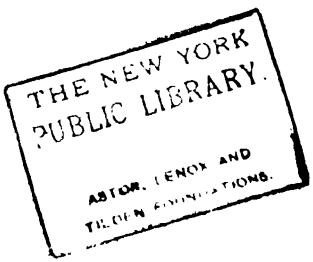
insertion of even 1 ohm in series with the condenser of a high-frequency spark coil markedly increases the sparking at the primary contacts.

The value of the advance made by the introduction of foiled paper for condenser making lies in the fact that in this material the dielectric and the conductors are more correctly proportioned to their work than is possible when solid metal foil is used. Owing, therefore, to what may be called the better design of the foiled-paper condenser, it is correspondingly cheaper, lighter, and smaller. Even with foiled paper, although the quantity of metal per unit area is extremely small, the conductance of the electrodes is in excess of the actual requirements, whilst if solid foil is employed, it is necessary to use fully ten times the weight and volume of metal that would suffice if only the conductance had to be considered. The necessity arises from the fact that metal foil cannot be rolled in continuous lengths to give a greater covering surface than about 90 sq. ft. per pound (about 18½ sq. metres per kilogramme), and even with this thickness the foil is extremely tender and requires delicate handling, as, if made of pure tin, it is only 0·0003 in. thick. The metal foil is in addition expensive, and is by far the most costly item in the construction of a condenser. Further, when metallic foil is used, short circuits are very apt to develop both during manufacture and in subsequent use. The short circuits are due to grit in the foil, or to pinholes or other defects in the interleaving paper, or are consequent upon disruptive discharges caused by the application of a voltage in excess of the dielectric strength.

Now with respect to these short circuits or disruptive discharges, however produced, condensers made of foiled paper have the peculiar advantage of possessing to an almost perfect degree the property which in a pneumatic tyre is called self-sealing, and consequently they are practically proof against short circuit, and can be subjected to much higher voltages than is permissible with those made from metallic foil, any momentary short circuits produced by a disruptive discharge being instantly and automatically sealed. This automatic sealing is brought about in the following way: owing to the extreme thinness of the conducting film the small quantity of heat generated at the point of short circuit by the sudden discharge of the condenser through that point is sufficient to cause the film of metal immediately surrounding the point of breakdown to be fused into minute globules. The segregation of these globules from each other and from the surrounding metallised surfaces effectually isolates the point of breakdown, and the defect is instantaneously sealed up. So rapid, indeed, is this effect, that if a pin is stuck into an insulated charged condenser so as to produce short circuits between the foiled papers, the short circuits seal up without fully discharging the condenser, and a dozen or more of such short circuits may be created one after the other before the condenser becomes fully discharged. Consequent upon the observation of such an effect as this, the author conceived the idea of electrically treating



FIG. 1.—Micro-photograph of a "Breakdown Point" after Electrical Treatment.


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the foiled paper before making it up into condensers in such a way as practically to eliminate all pinholes or defective places by subjecting them momentarily to currents of such strength as to produce a minute non-conducting ring round each defect, thereby isolating it from the surrounding surface.* The apparatus for doing this is of the simplest character. All that is necessary is to pass the paper, foiled side uppermost, over a conducting roller, and to maintain a suitable potential difference between the roller and the foiled surface. When any pinhole or weak place in the paper reaches the roller a short circuit occurs, and the momentary rush of current, concentrated round the defect, produces a bright spark at the defective spot on the foiled surface. As in the case of the finished condenser, the effect of this spark is to isolate the defect by volatilising or fusing the film of metal immediately around it. In this way all the weak places in the dielectric are detected and isolated before the paper is brought into use, and in consequence it is possible to use thinner paper, both foiled and plain, than would otherwise be safe. The process of isolating or removing these faults is quite automatic, and the apparatus once set requires practically no adjustment; all that is necessary in this respect is to see that the current at the moment of short-circuiting is sufficiently strong to fuse the metallic film in the immediate neighbourhood of the defect but is not so strong as to burn the paper. If current from lighting mains is employed a series resistance is necessary to limit the short-circuit current. With 100 volts this resistance should be about 15 ohms, and with 200 volts about 150 ohms. Experience shows that the searching effect of the voltage is increased by connecting a condenser of considerable capacity, say 20 microfarads, across the potential terminals, but a series resistance of about 50 ohms in the condenser circuit is needed to tone down the suddenness of the condenser discharge.

The values given above for voltage, capacity, and resistance, are in no sense "critical," and they may be varied considerably without seriously affecting the result; in adjusting the values the best conditions may easily be found if regard be had to the fact that the result desired is the production of a small uncharred hole surrounded by a minute ring of perfectly clean white paper. Fig. 1 is a microphotograph of a typical "breakdown" point after treatment by the aforementioned process. The hole made by the spark is shown as a dark spot, and the ring of paper from which the metal has been completely removed may be seen round the hole, although the want of contrast between the polished metallic surface and the white paper renders the ring somewhat indistinct in the photograph.

As the process of eliminating these defective places in the paper is largely one of breaking down the weak spots, the operation is generally described as the "breakdown process." The voltage used may conveniently be one-half of that with which the finished condenser is finally to be tested, that is, if only single interleaving papers are to be used. If the condensers are to be made for 1,000 volts or thereabouts

* U.K. Patent 22139, 1905, G. F. Mansbridge.

it is necessary to use double or treble interleaving papers, and in this case the obvious course is to fix the breakdown pressure at a figure which will result in the dielectric of the foiled paper being strained during the breakdown process to an extent rather greater than will be the case when it is finally used. The author's experience is, however, that the majority of defects are shown up and removed by a comparatively low voltage, and that there is little to be gained by using more than 200 volts for this process if the condensers are for telephone or telegraph work. As regards the direction of the current there appears to be little to choose; if anything, the preference may be given to connecting the positive pole to the plain side of the paper, but the device works quite satisfactorily with alternating current. When the breakdown device is driven by an electric motor it is of advantage to have two rollers making contact with the foiled side of the paper at separate points, preferably not less than 2 ft. apart; the current driving the motor may then be led along this strip of foiled paper between the two rollers, so that should there be any break in continuity in the foiled surface the current driving the motor would be broken when the fault passed the first roller, and the stopping of the machine would call attention to the want of continuity. With paper made by reputable makers such breaks rarely occur, but there must always be a risk of this, and as the device is simple and automatic it is worth while to adopt it. Fig. 2 shows the connections of the breakdown rollers as arranged for motor driving.

If the apparatus is mechanically driven, a suitable relay may be connected between the second and fourth rollers so that a local circuit is completed and a bell rung whenever there is any break of continuity between the two rollers.

Joints in the paper may have to be made from time to time. These must, of course, be made electrically continuous, and a simple way of effecting this is, after the ends have been joined by lapping and pasting in the ordinary way, to paste on to the foiled surface a 6-in. strip of foiled paper placed face downwards, so that part of the foiled surface of the strip makes contact with one side of the break and part with the other. It is not desirable to paste the whole of the surface of the strip, since the continuity of the film may thereby be destroyed; the usual plan is to paste merely the edges on each side, leaving the middle portion clean. Good flour paste is found to give satisfactory results.

The condenser plates having been wound then pass to the drying oven, and subsequently to the vacuum pans and screw-presses. The desiccation of the plates prior to waxing must be very complete and thorough if the highest insulation is required. Ovens heated by gas, steam, and electricity are in use for this purpose, but the last-named is infinitely preferable. The ease with which the temperature can be controlled, and particularly the facility with which the heat can be kept to its legitimate purpose instead of being dissipated throughout the shop, and the absence of objectionable fumes and of steam joints, which always give trouble sooner or later, are advantages sufficient to

place this form of oven easily first. For an oven of about 25 cub. ft. capacity which will accommodate five hundred 2-microfarad plates, a power consumption of 2 k.w. suffices. The length of time necessary to produce thorough desiccation depends upon the temperature of drying, the relative dryness of the air, and the degree of contact between the hot air and the paper. The temperature permissible is limited by the necessity to avoid scorching the paper, since cellulose suffers adverse physical changes if heated much above 212° Fahr. for any considerable time. Consequently the practice at one time was to dry the condensers at a temperature of 212–220° Fahr., but this involved from three to four days' stoving unless the plates were composed of only a very

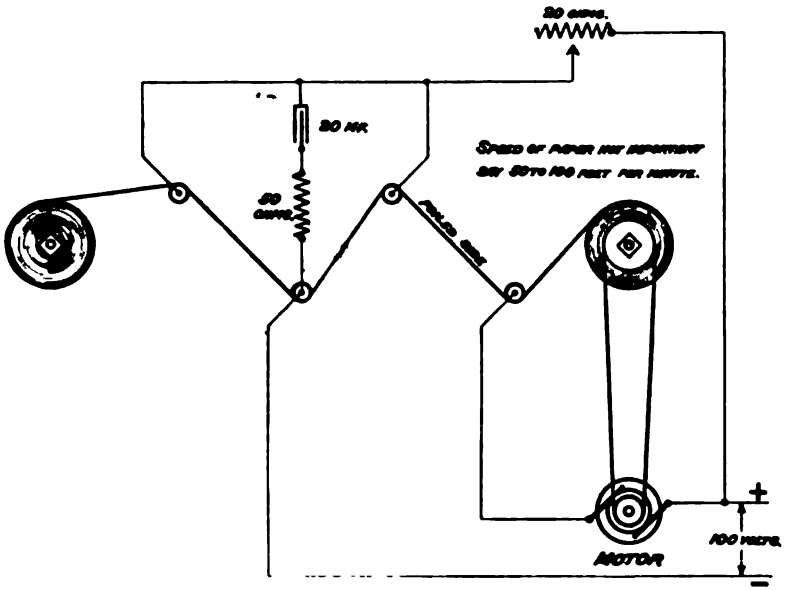


FIG. 2.—Device for treating Tinfoil Paper.

few sheets or layers, and were disposed in such a way that the heat could readily permeate, and the moisture readily leave, the innermost layers. This in commercial work is impracticable, since some condensers of ordinary size have over 100 convolutions, that is, 800 layers of paper in the flat roll, and a great many have to be accommodated in the oven at the same time. In seeking for means to introduce heat into the interior of the condenser, and thereby to expedite the drying process, the author tried the plan of utilising the resistance of the strip of foiled paper to generate heat in the interior of the condenser when a current of suitable strength was passed along it. To this end all that was necessary was temporarily to short-circuit the plate by means of the connecting lugs at the commencement of the

roll, and to pass the current in at another pair of lugs at the end of the roll. It was found in this way, that with an oven temperature of 212° Fahr., and an additional expenditure of 4 watts per 2 microfarad plate, thorough desiccation could be effected in 8 to 12 hours, without any scorching of the paper, although the temperature inside the rolled condenser reached 270° Fahr. Although fairly simple in manipulation, this method did not lend itself very readily to commercial manufacture on the large scale, but it served to point the way to the possibility of using higher temperatures without scorching, and it eventually led to the use of a simple process which has been found most satisfactory and efficient, namely, the vigorous churning of the heated air inside the oven by means of a fan. This rapid circulation results in a great number of particles of heated air being brought into contact with the paper in a given time, and as a result of numerous trials it is found that the use of a fan in this way permits of temperatures as high as 290° or 300° Fahr. being employed without scorching the paper. It will be understood that the fan does not create a circulation of air from outside, but merely churns the hot air in the oven, and although after a time this air becomes more or less moisture-laden, the high temperature enables it to absorb an enormous weight of water before reaching saturation point. By running up the temperature in this way satisfactory desiccation can be obtained in as short a time as 8 hours, and this quick drying is of very great advantage where a large output has to be maintained.

Fig. 3 is a graph of the insulation of various batches of foiled-paper condensers which were subjected to different periods of drying under the conditions indicated above.

One point calling for attention as regards the drying of condensers is the shrinkage in length which takes place with many papers during desiccation. In the case of plain paper newly come from the mill, this may amount to ½ per cent. after 24 hours' drying at 212° Fahr., and there is a further shrinkage on waxing. In the case of foiled paper the shrinkage on drying is much less, and the whole of this occurs prior to waxing. If perfectly fresh and undried interleaving paper is wound up tightly with foiled paper and the compound roll is then dried and waxed, there will be a tendency for the great shrinkage of the interleaving paper to cause the foiled paper to crinkle or crease when pressed. To guard against this, the plain paper should either be matured for a few months in stock, by which time it will have shrunk considerably, or it should be oven-dried for some hours before use.

After being effectively desiccated the plates have to be impregnated with paraffin wax. The function of the paraffin is three-fold :—

1. To increase the inductive capacity of the dielectric.
2. To prevent moisture from again reaching the highly hygroscopic paper.
3. To retain the condenser in the closely compacted form into which it is compressed while the wax is hot.

The inductive capacity of the layers of paper and air which separate the electrodes before the plate is impregnated is approximately 1·2, and on the air being replaced by paraffin this increases to approximately 3·2. Obviously the more thoroughly the air is replaced by the paraffin the greater will be the gain, and to facilitate this it is advantageous to impregnate the condensers *in vacuo*. Hot wax very readily penetrates paper, and it might be thought that soaking for several hours in paraffin

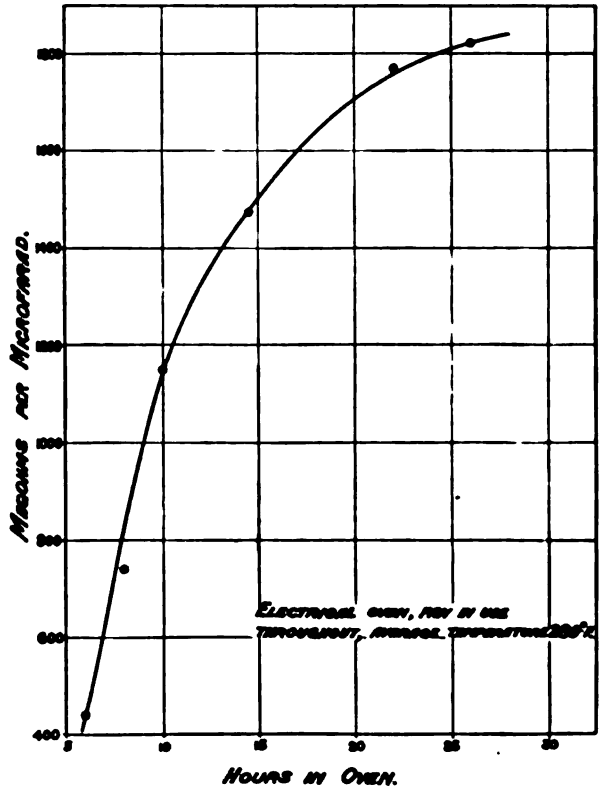


FIG. 3.—Foiled Paper Condensers. Average Insulation (300 Volts, 60 Seconds, 60° Fahr.) after various Periods of Drying.

at 212° Fahr. would suffice thoroughly to impregnate the paper, but as the result of tests of some batches aggregating a thousand plates it was found that the gain in capacity due to impregnation under vacuum averaed 11 per cent. This means that by using the vacuum process 11 per cent. less material is required for a given capacity, while in addition the condenser produced is more reliable, since every isolated air-bubble entangled in the interior tends to reduce the dielectric strength by causing unequal distribution of strain, and also tends, by

expansion and contraction, to cause, in time, a drop in capacity by separating the layers, and a drop in insulation by affording an opportunity for moisture to enter the interior of the plate. An obvious way of impregnating *in vacuo* is to exhaust the air from the pan containing the condensers, and then after complete evacuation to run in the hot paraffin; but equally good results can be obtained by simple exhaustion over the wax, that is to say, by plunging the plates into a pan of hot wax, fastening the lid, and then maintaining a vacuum in the upper portion of the pan. The advantage of the latter plan is as follows. In order to facilitate the exhaustion it is necessary to heat the paper; this heat can most conveniently be conveyed into the inside layers of paper by means of the hot wax. If the exhaustion is carried out with the paper dry there is no vehicle to carry the heat into the interior of the condensers, and only radiated heat from the sides of the pan is effective, since the air has been withdrawn; for other reasons also the plan of evacuating over the wax is found to have the balance of advantage. A photograph of a convenient form of vacuum pan is shown on the screen. This pan is gas-heated and will accommodate 150 2-microfarad plates per charge. To prevent deterioration of the paraffin by scorching, the bottom of the pan is made exceptionally thick and several rows of minute gas jets are provided so as to distribute the heat uniformly over the bottom. To facilitate the circulation of the hot wax the plates are not allowed to rest upon the pan itself, but are laid upon a loose metal grid which stands up an inch or so from the bottom of the pan. Two hours impregnation at 212° Fahr. is sufficient if a thoroughly good vacuum is obtained. After full impregnation the vacuum is broken and the condensers are left subjected to atmospheric pressure for ten minutes, and are then removed from the hot wax and at once pressed. No advantage can be traced from the employment of more than atmospheric pressure in the pan after evacuation is complete. The method of pressing and the manipulation at this stage are of considerable importance, and it may therefore be well to describe this operation in detail. In the first place it will be obvious that the greater the pressure the greater, within limits, will be the capacity obtained, and with this object it is the practice in certain factories to employ hydraulic machinery and to compress the plates to the utmost limit. The objections to this course are, however, considerable. First, there is a great tendency to drive the paraffin out of the pores of the paper and so to leave the paper readily penetrable by moisture, unless the plates are at once hermetically sealed. Secondly, the enormous pressure greatly increases the liability to short circuits, and although this is of little importance with foiled-paper condensers owing to the automatic sealing, it is better to avoid it since such breakdowns after the paper has been waxed are always accompanied by a fall in insulation. Thirdly, the excessive pressure results in lowering the insulation to an extent which is out of proportion to the increased capacity. This effect, which is shown graphically in Fig. 4, necessarily follows from the reduction in the proportion of paraffin to paper, since

the wax has much the higher specific insulation. A further objection to hydraulic pressing is that for commercial reasons it involves the simultaneous pressing of a vertical pile of plates, and this procedure is to be deprecated since the cooling of such a pile is necessarily slow, and the wax continues to drain out of the inner condensers to such an extent that when cold there is comparatively little left in them. As the result of experience, it can be said that for a condenser which is

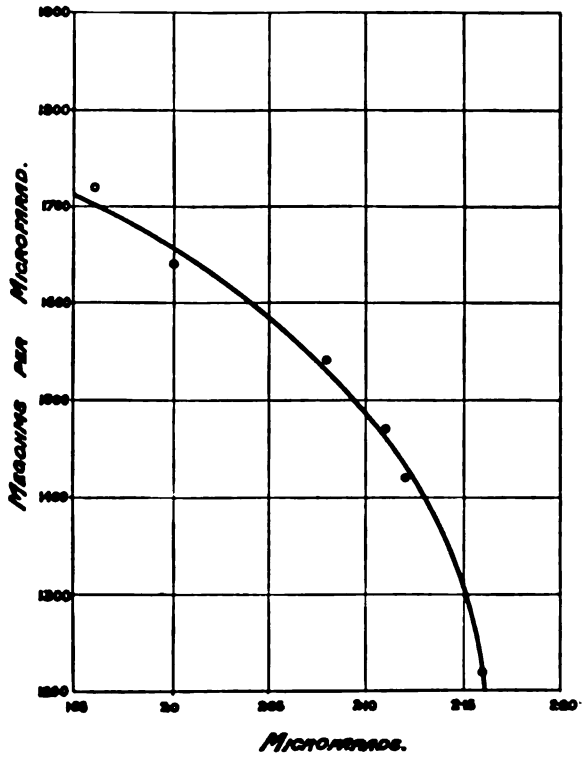


FIG. 4.—Foiled Paper Condensers. Relation between Capacity and Insulation of similar Condensers, subjected to differing Degrees of Mechanical Pressure.

required to maintain its insulation and capacity for many years it is of first importance that a good body of wax be left in the plate. For this reason the pressing of even two plates one above the other is not permitted at the Post Office factory. The same objections do not, of course, apply to the pressing of a number of plates side by side; indeed, this is the current practice, and it is found to give satisfactory results. With the same object—namely, that of retaining a sufficiency of wax in the plate, the presses are water-cooled both

on the top and on the bottom. This water-cooling, in addition to the technical advantage referred to, has also the commercial advantage of increasing the output of the presses, which is of importance now that condenser manufacture is carried out on such a large scale. With cooling water at a temperature not exceeding 60° Fahr. five minutes' cooling in the press suffices for a condenser $\frac{1}{4}$ in. thick; for plates of greater thickness a correspondingly longer time is necessary. The presses are of the screw type, and the question naturally arises as to why this form is adopted in preference to the apparently more scientific method of a lever and dead weights. Contrary to what might be expected, experience shows that more uniform results can be obtained with screw-presses than with levers and dead weights, and the latter form has consequently been altogether abandoned at the Post Office factory. Even the use of gauge-blocks for the screw-presses, by means of which the condensers are pressed to a certain definite thickness, seems to give less uniform results than can be obtained by a careful workman with a little practice, without any guide other than the "feel" of the press, and an occasional capacity test of the plates as they come from the presses. One objection to the gauge-blocks is that they do not allow for the small commercial variations which are constantly met with in condenser manufacture, and another is that they tend to reduce the operation of pressing, which is one that really requires some little skill and care, to the mere manipulation of a machine.

As soon as the plates are fairly cold they should be placed aside to settle down in temperature before being tested, and in the meantime they should be protected from atmospheric moisture. Paraffin, contrary to the opinion of the layman, is markedly hygroscopic, and it is important that the outer layer of wax should not be allowed to absorb moisture before the condenser is hermetically sealed; otherwise the insulation will steadily fall, as the moisture diffuses throughout the mass.

In addition to or in substitution of paraffin, various waxes and mixtures have from time to time been proposed for condenser work. Beeswax, resin, shellac, ceresine, stearine, lead stearate, etc., have all been suggested, and for each some special advantage has been claimed in the way of higher inductive capacity, greater dielectric strength, or less affinity for moisture as compared with paraffin. The author has, however, been unable to find that any one of these substitutes possesses the all-round advantages of good paraffin; this material, plain and unadulterated, is therefore recommended save for special cases where a peculiar property of one or other of the substitutes may justify its use to meet the peculiar conditions. For condenser work a high quality of wax is necessary, but this does not necessarily imply a high price or a high melting-point. For use in tropical countries paraffin of a specially high melting-point is desirable, but for use in the temperate zones wax with a melting-point of about 130° Fahr. answers most requirements. The melting-point or, more correctly, the "setting"-point, may be

determined in a very simple way, although various methods of a more elaborate character find favour in some chemical laboratories. The plan adopted by the author is to insert a calibrated thermometer with a small bulb into a vessel of hot wax, and as the wax cools to observe the fall of temperature with respect to time. If the thermometer and the quantity of wax are suitably chosen there will be a well-defined period during which the temperature becomes stationary; this temperature represents the setting-point. The observation can be repeated by

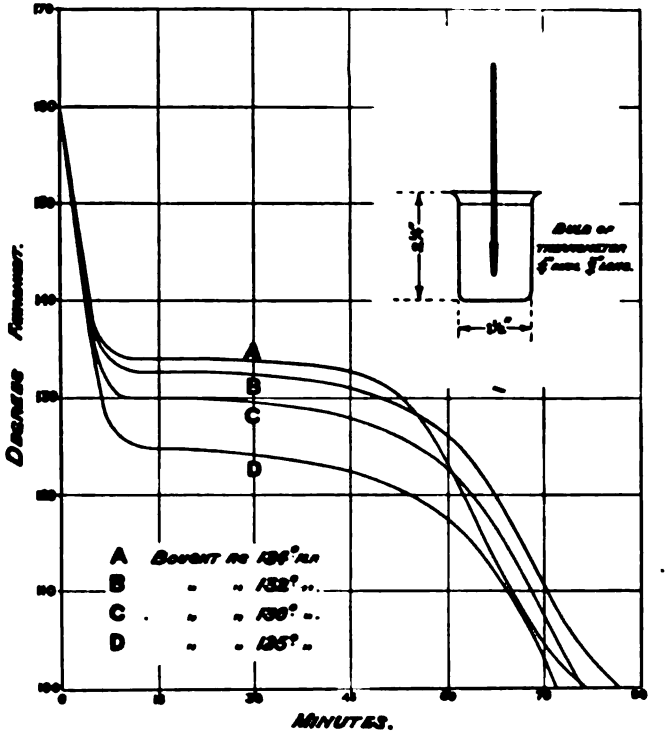


FIG. 5.—Cooling Curves for Paraffin Wax.

different unskilled observers with identical results, provided that the local conditions are approximately the same for each observation. Some typical curves showing the result of this method are reproduced in Fig. 5. A convenient quantity of paraffin is about 2 oz. contained in a test tube or beaker 1¼ in. in diameter; the thermometer generally used has a bulb of ¼ in. diameter by ¾ in. long. If a thermometer with a very large bulb is used the effect may be partially masked, since the quantity of latent heat given out by the paraffin on solidifying is not great, but even under these conditions the setting-point may be estimated very closely.

For condenser work the wax cannot be considered satisfactory unless it is chemically neutral and free from unsaturated hydrocarbons. Its suitability in this respect can readily be ascertained by the usual chemical tests.

Before being run into the vacuum pan the wax should be strained through sieves of the finest mesh (a few thicknesses of muslin will answer very well) to remove mechanical impurities.

In all stages of condenser manufacture handling by the workmen should be restricted to a minimum, and no operative who is inclined to perspire freely should on any account be permitted to handle the plates prior to boxing. Paraffin readily absorbs the moisture and salts of the body, and a condenser plate, once contaminated in this way, will have a short life so far as insulation is concerned. From this point of view the ideal method of manufacture is to place the dried plates in metallic cases, to plunge the whole into the hot wax, then to exhaust the air, and finally to take out the condenser complete in its case so that the plate after impregnation suffers no handling whatever. The objections to this plan are that there is so little control over the capacity, and that there is such great waste of material, since the pressure which can be brought to bear is so small; the method can, however, be recommended where long life is of more importance than first cost.

In default of reaching the ideal, the best that can be done commercially is to handle the plates as little as possible and to seal them hermetically in metal cases as soon as possible after manufacture, and this is the course adopted at the Post Office factory. Reference has already been made to the question of dielectric strength. As is well known, this, with paraffined paper, is apt to be a very variable quantity, particularly when—as with most commercial condensers—the electrodes are separated by only two thicknesses of paper, since a weak spot in one of them so largely reduces the resistance to disruptive discharge.

As a rough approximation, it may be said that with ordinary paraffined paper at 60° Fahr. the breakdown-point is approached when the pressure reaches the equivalent of 150,000 volts per centimetre. With foiled paper, however, the result of the automatic sealing is practically to double the effective dielectric strength.

Fig. 6 shows graphically the results obtained on subjecting an ordinary telephone condenser, made from foiled paper, to steadily increased pressure. As the voltage rose above the normal point of dielectric strength the paper broke down, possibly at several places, but each short circuit sealed up as fast as it was formed, and not until the pressure reached 1,200 volts was the condenser rendered useless.

For telegraph condensers, which are generally required to be adjustable, an outer wooden case carrying a peg-switch is provided; the internal construction is as follows. Separate condensers of suitable capacity are selected, and after a preliminary test are assembled between a pair of sheet-iron plates, which are then bolted together. The object of these clamping plates is two-fold; first, to build up the separate condensers into a substantial mechanical structure; and

secondly, to keep upon them a certain degree of pressure so as to counteract the natural tendency towards a drop in capacity. The batch of plates so assembled is built up into a solid mass with plastic paraffin, and is then hermetically sealed in a tinned-iron case, the opening where the wires are brought out being sealed with a non-contracting mixture of gutta-percha, resin, stearine pitch, and Stockholm tar.*

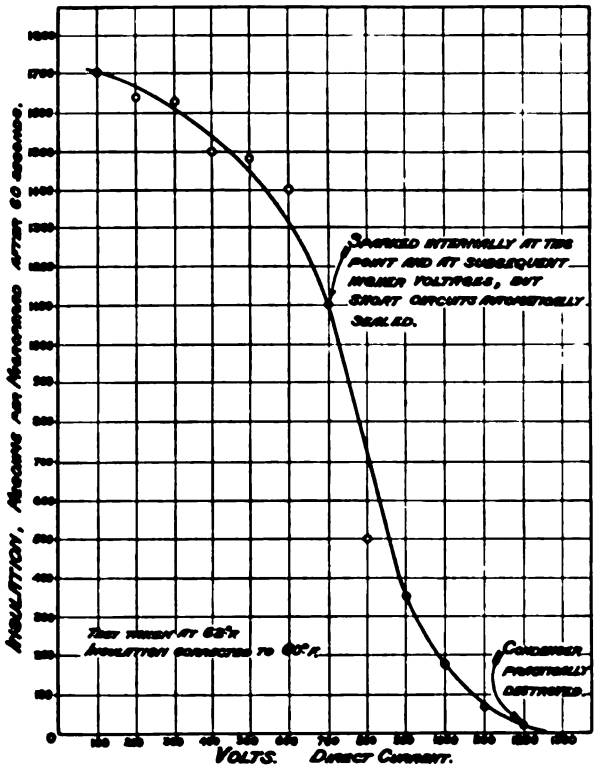


FIG. 6.—Foiled Paper Condensers. Curve showing Relation between Testing Voltage and Observed Insulation.

This compound does not flow at high temperatures, does not get brittle when frozen, adheres firmly to metal surfaces, and contracts

* The mixture consists of :—

Gutta-percha scrap	...	...	...	20 parts
Resin ...	...	...	...	14 ,,
Stearine pitch ...	...	...	...	6 ,,
Stockholm tar ...	...	...	...	14 ,,

Commercial stearine pitch varies considerably in hardness, and if the mixture so made proves too hard it may be tempered by the addition of a little boiled linseed oil.

very little on cooling. The same mixture is used for sealing the top of the tin cases of telephone condensers, the metal cap which is subsequently soldered in position being merely a mechanical protection.

For telephone work nothing more is necessary than a hermetically sealed metal case, since the condenser is usually covered up and protected by the telephone apparatus. On the Continent papier-mâché cases have been adopted to some extent, but their use cannot be recommended, since papier-mâché readily absorbs moisture, and in consequence the insulation of a condenser contained in a case of such material cannot be relied upon for any length of time. Such cases are cheaper to make than metal ones, and they obviate any risk of contact between two circuits *viâ* the cases of two contiguous condensers, each of which has developed contact with one of the contained electrodes, but inasmuch as satisfactory and lasting insulation between the electrodes and the case is obtainable with ordinary care there would seem to be no sufficient reason for the employment of such an untrustworthy material as papier-mâché.

In speaking of the insulation resistance of a condenser it is necessary to be most precise as to exactly what is meant. The insulation is usually expressed either in terms of the percentage loss of charge after the charged condenser has been insulated for a certain time or as so many megohms per microfarad. The "percentage-loss-of-charge" method is used chiefly for standards and for submarine cable condensers; for ordinary telegraph and telephone condensers the insulation is more often reckoned as "megohms-per-microfarad." Neither expression is a precise specification of the insulation value unless certain datum lines are assumed or stated. The first of these necessary data is the temperature at which the test is taken, the second is the value of the voltage applied, and the third is the time which is allowed to elapse between the first application of the voltage and the moment at which the leakage is measured. For the loss-of-charge method the periods of charge and of insulation have to be stipulated. The latter period is commonly taken as 1 minute, but the period of charge is not so well standardised, 15 seconds being taken by some observers and 60 seconds by others. The pressure often employed for this test is 100 volts. Of the scanty literature on this subject the most noteworthy seems to be that contained in an article * by Messrs. Dearlove and Sayers, who have given the results of some interesting experiments made by them on tinfoil and paper condensers as made for submarine telegraph work.

With respect to temperature, 60° Fahr. is in this country the standard generally accepted for tests made by both methods.

The voltage adopted for the "direct deflection" or megohms-per-microfarad method varies according to the nature of the duty demanded of the condenser. The period of application of the pressure in this case is usually 2 minutes; the leakage is measured at the 60th second after the moment of application, and the insulation is calculated

* *Electrical Engineering*, March 21, 1907, "Relative Dielectric Resistance at various Temperatures of Paraffined Paper Condensers."

on the basis of that moment's reading. During the whole period of the test the leakage should steadily decrease; and as a measure of this absorption or "electrification," it is usual to take the difference between the readings at the end of the 60th and the 120th second respectively, and to express this difference as a percentage of the reading at the 60th second. With a good condenser

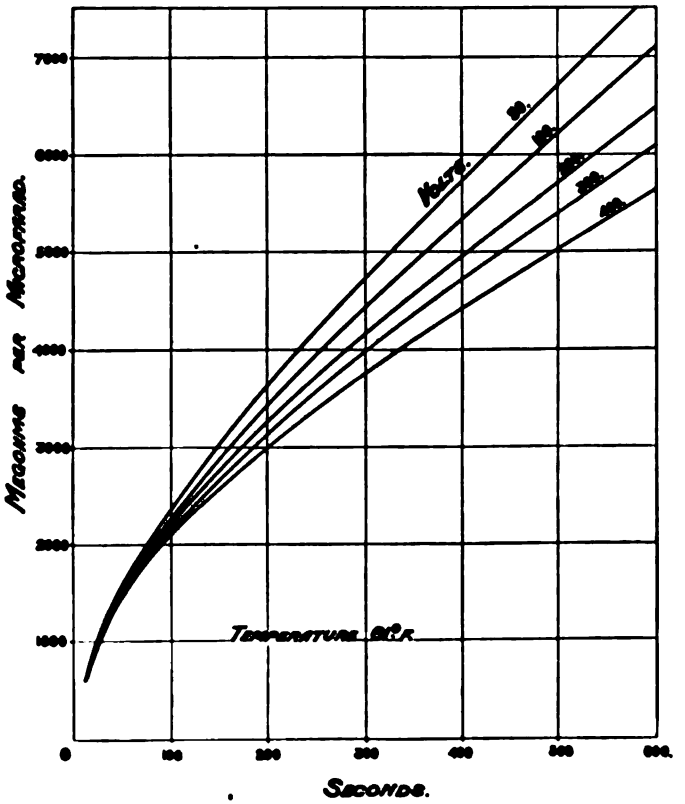


FIG. 7.—Foiled Paper Condensers. Insulation and Electrification with various Voltages.

this percentage will usually fall between 25 and 35 if the test is taken at 60° Fahr. The degree of electrification falls markedly with a rise in temperature. The behaviour of a condenser in respect to electrification is an important indication of its quality, as incipient defects give the first indication of their existence by producing unsteady or "negative" electrification. Fig. 7 shows typical insulation and electrification curves of foiled-paper condensers when tested with various voltages. The relation between time and insulation, and also between

voltage and insulation, is clearly shown by these curves, and it needs only a glance at them to see how necessary it is closely to specify the precise data of any test. Fig. 8 shows similarly the variation of insulation with constant voltage and varying temperature, the tests being taken after 1 minute's application of the voltage, the temperature in each case being maintained for a period long enough to allow the condenser thoroughly to take up the new temperature. As may be

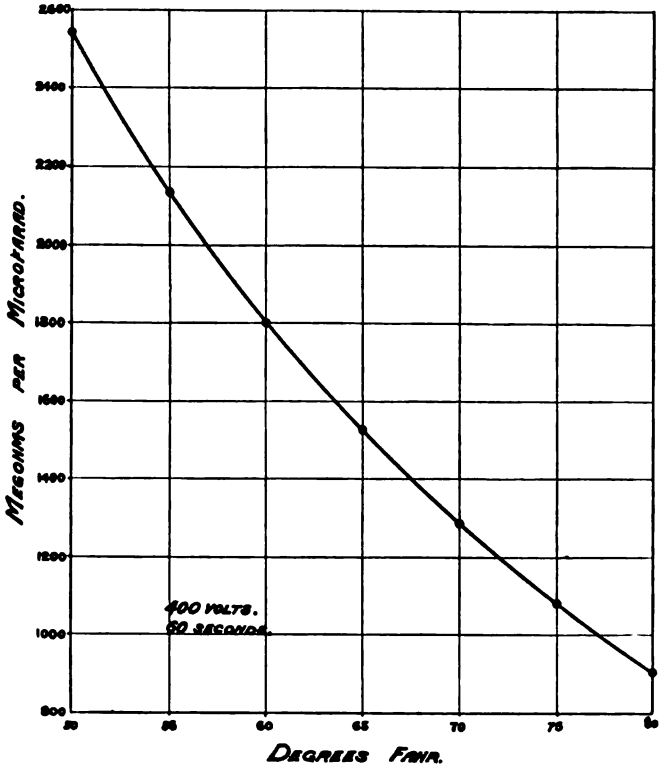


FIG. 8.—Foiled Paper Condensers. Variation of Insulation with Temperature. (Curve plotted from calculated figures.)

deduced from the curve, the correcting coefficient for foiled-paper condensers is as nearly as possible 3·50 per cent. per degree Fahr. or $Y_{60} = Y_t\, 1{\cdot}035^{t-60}$, where Y_t and Y_{60} are respectively the observed insulation resistance at $t°$ Fahr. and the corrected insulation resistance at the standard temperature of 60° Fahr. This assumes that the insulation is measured after 60 seconds' application of a pressure of several hundred volts. It is not suggested that this formula has an accuracy which is comparable with that of a copper-resistance temperature

coefficient, since the difficulties of measurement are so much greater in the former case, but it is thought that the formula will be found generally to give, over a considerable range of temperature on both sides of 60° Fahr., results sufficiently accurate for commercial purposes.

From general considerations one may anticipate the existence of a relation such as—

$$\Omega \propto \frac{s}{v^{t}}$$

where—

Ω = megohms per microfarad.
s = seconds after application of voltage.
t = temperature in degrees Fahr.
v = applied voltage.

Analysis of a number of insulation and electrification curves shows that the relation may be expressed in a simple numerical form, and for foiled-paper condensers the following approximate empirical formula is obtained :—

$$\Omega = 400 \frac{s^{\cdot 5}}{v^{\cdot 1} \times 1{\cdot}035^{t-60}}.$$

For metallic-foil condensers the expression becomes—

$$\Omega = 4{,}000 \frac{s^{\cdot 5}}{v^{\cdot 1} \times 1{\cdot}035^{t-60}}.$$

These empirical formulæ are, of course, only applicable to thoroughly desiccated condensers properly constructed of good material.

A special development of the paper condenser is the "inductive-resistance" form introduced by Dr. Alexander Muirhead for the balancing of long submarine cables. The onerous conditions of duplex working on a long cable call for an artificial line whose electrical constants in all respects approximate closely to those of the real cable. The difficulty in constructing such artificial cables lies in the fact that the constants to be matched are so many ; the artificial line must match the real line in resistance and capacity, both in the aggregate and as regards distribution, and at the same time the insulation resistance and electrification must be similar in the two lines. These conditions are closely met by the Muirhead grid type of condenser. This, as is well known, differs only from the tinfoil condenser in that one set of electrodes consists of plain sheets bunched together, while the other set consists of sheets of foil cut into the form of a grid. The strips forming the grid are joined in series and serve as a resistance. The width of the strips may be chosen so as to give within a considerable range any desired ratio between resistance and capacity. The insulation and electrification constants are not so easily matched with accuracy, but fortunately the insulation and electrification of high-class condensers made from thoroughly desiccated paper impregnated with paraffin are of the same order as those of a gutta-percha submarine cable, and an exact match of these constants is not essential. To adjust the capacity and resistance of such an artificial line to a definite

value at standard temperature is not difficult, since, for commercial reasons, such condensers are invariably made up from a number of separate plates, and although each of these may be expected to have some variation from the precise figure aimed at, yet by combining high and low plates together the aggregate may be made to agree very closely with the desired figure, and the final adjustment may then be made as with a resistance coil.

The question of maintaining the conductor resistance of such a condenser constant under varying temperatures is a more difficult problem, and is one which, so far as the author is aware, has not been successfully solved; the usual method is to get round the difficulty rather than over it by choosing a situation for the artificial cable where the temperature variations are reduced to a minimum.

The manufacture of such artificial cables is very expensive, owing to the difficulty in handling the thin grid of tinfoil; this may, however, be overcome by the use of foiled paper, since owing to the thinness of the conducting film the strips are much wider than if made of metal, and they are consequently more easily handled. In illustration of this it may be said that artificial cables of very high $\frac{\text{resistance}}{\text{capacity}}$ ratio have been constructed of foiled-paper strip without difficulty. For example, some have been made to match 20-lb. conductor paper-insulated telephone cable, which has a resistance of 44 ohms per mile and a distributed capacity of 0·054 microfarad per mile. Such a proportion with solid metal strip would offer great manufacturing difficulty, particularly as for artificial telephone cables it is necessary that both electrodes be of the strip form; for submarine cables with single conductors the plates are alternately strip and sheet. It should, however, be observed that the insulation obtainable from metallic strip and plain paper is higher than is obtainable from ordinary foiled paper, but by specially preparing the foiled paper this difficulty could probably be overcome.

The workshop apparatus required for testing condensers during and after manufacture depends, to a certain extent, upon the conditions of service. Assuming that the condensers are required to comply with the requirements of the Post Office Specification, the most satisfactory testing set will be found to be a good strained-suspension reflecting galvanometer, carefully calibrated for proportional throws and deflections, together with the usual universal shunt-box, short circuit, and reversing keys, and a primary or secondary battery giving at least 400 volts. Dry cells of modern types and of not too small capacity give satisfactory service for two years or more, but care must be taken to insulate them satisfactorily. The galvanometer and other testing instruments must be carefully "guard-wired," otherwise the tests will be more or less vitiated by leakage. No difficulty has been found in training ordinary workmen to use reflecting galvanometers intelligently and without damage. The strained suspension is of great value in overcoming difficulties due to vibration of the building.

The specification of the National Telephone Company provides for tests of a less simple character. These tests involve the use of sinusoidal alternating currents of speaking and ringing frequencies, and require apparatus of special construction.

By the courtesy of the National Telephone Company, Ltd., the author is able to quote in the Appendix the technical details of this specification.

IV. *Electrolytic Cells.*—These have not been received with much favour in this country, but they were at one time used to a considerable extent in Germany for common battery telephone work. They have, however, been almost entirely discarded in favour of paraffined-paper condensers. The only advantage which these "polarisation cells" possess over condensers is with respect to size, a cell, or a set of cells, capable of stemming back a direct current of 25 volts having a volume of only about 5 cub. in. On the other hand, the cost of such a set of cells is from three to four times that of a condenser of equal effectiveness. The cells used appear to be of three classes, viz.: "Acid cells," consisting of two small electrodes of platinum dipping into an acid solution; "sodium cells" (natronzellen), in which the electrolyte is a solution of a sodium salt; and aluminium cells, in which the electrodes consist of aluminium, and the electrolyte is some kind of basic solution. The acid cells have a damming effect of about 1·8 volt each, the sodium cells about 2·7 volts, and the aluminium cells as much as 30 or more volts. It is probable that the polarisation cell would never have been developed as a practical device if the modern condenser had been available at a reasonable price in the early stages of telephone development. The disadvantage of the polarisation cell is that it is more or less leaky, both electrically and mechanically. The permanent polarisation current passing through each cell is small, but on a system of many thousand subscribers the aggregate leakage becomes considerable. The mechanical difficulty is, however, the more serious one. If the cells are hermetically sealed they are liable to burst owing to the gradual accumulation of gas, which has been known to cause pressures up to 20 atmospheres. To avoid this difficulty some forms are provided with a simple release valve. This is particularly necessary with aluminium cells, as these are of larger size and evolve a greater quantity of gas. It is, however, almost impracticable to prevent some leakage of the solution, and in all the circumstances it is not surprising that the chemical cell has been ousted by the static condenser.

APPENDIX.

Post Office Specification for Condensers, Wooden Cased, for Telegraph Purposes.

The plates to be secured between substantial iron clamps and to be boxed up solid and air-tight with an approved insulating compound, the clamp being secured to the side of the case by means of suitable lugs and screws.

The capacity of each section to be not more than 5 per cent. higher or lower than the nominal value in the case of plates of 1 microfarad and above, and not more than 10 per cent. higher or lower in the case of capacities of less than 1 microfarad, and, in the case of signalling condensers, the difference between the two halves of the condenser to be not more than 0·25 microfarad.

The capacity of each section to be measured by taking the instantaneous discharge after the section has been charged for a period of 10 seconds with an electromotive force of 30 volts.

Each condenser will be tested for insulation and electrification, but these tests will be taken on the condenser as a whole and not on the separate sections, and the tests will be taken with an E.M.F. of 400 volts as follows: The condenser being at a temperature of approximately 60° Fahr., apply the battery for a period of two minutes. The deflection shown after one minute must indicate such an insulation resistance in megohms that when multiplied by the capacity in microfarads the product shall be not less than 1,000. The deflection shall steadily decrease during the second minute, and the difference between the readings at the beginning and end of the second minute shall be not less than 20 per cent. of the first minute reading for 1 microfarad and the larger sized condensers, and 10 per cent. of the first minute reading for condensers less than 1 microfarad, but including 0·5 + 0·5.

The case to be of best well-seasoned Spanish mahogany and to be thoroughly French polished.

Post Office Specification for Condensers, Metal Cased, for Telephone Purposes.

The overall length, width, and thickness of the complete condenser, including the outside soldering tags, not to exceed the following dimensions, viz.:—

For condensers	0·5 mfd.	...	$4\frac{3}{4}$ in. × $2\frac{5}{8}$ in. × $\frac{6}{16}$ in.
,,	1·0 ,,	...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{6}{16}$ in.
,,	2·0 ,,	...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $\frac{9}{16}$ in.
,,	2·0 ,,	...	(square) $4\frac{3}{4}$ in. × $1\frac{5}{8}$ in. × $1\frac{5}{8}$ in.
,,	4·0 ,,	...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $1\frac{1}{8}$ in.
,,	10·0 ,,	...	$4\frac{3}{4}$ in. × $4\frac{3}{4}$ in. × $2\frac{1}{16}$ in.

The maximum total weight allowed for each type of condenser, complete with case, is as follows:—

0·5 mfd.	...	...	...	4 oz.
1·0 „	...	...	...	8 oz.
2·0 „	...	...	...	12 oz.
2·0 „	(square)	...	...	10 oz.
4·0 „	...	...	...	1 lb. 4 oz.
10·0 „	...	...	...	2 lbs. 14 oz.

The letters "G.P.O.," the manufacturer's approved code letter, the year of manufacture, and the nominal capacity of the condenser, to be plainly stamped on the metal case as on pattern. The stamping to be done before the condenser is inserted in the case. The actual capacity to be not more than 10 per cent. higher or lower than the marked value.

The capacity to be measured by taking the instantaneous discharge after the condenser has been charged for a period of 10 seconds with an E.M.F. of 30 volts.

Each condenser will be tested for insulation and electrification, but these tests will be taken on the condenser as a whole after fitting in the case and not on separate sections. The tests will be taken with an E.M.F. of 300 volts as follows: The condenser being at a temperature of approximately 60° Fahr., apply the battery for a period of two minutes. The deflection shown after one minute must indicate such an insulation resistance in megohms that when multiplied by the capacity in microfarads the product shall be not less than 300. The deflection shall steadily decrease during the second minute, and the difference between the readings at the beginning and the end of the second minute shall be not less than 20 per cent. of the first minute reading.

The insulation resistance between either of the outside soldering tags and the metal case to be not less than 300 megohms.

The condenser plates to be tightly fitted in the metal case and the top to be hermetically sealed before the metal top is put on. The sealing composition must not be brittle or so soft that it will flow at a temperature of 75° Fahr., and it must adhere firmly to the tinned iron case.

The ebonite strip carrying the tags to be securely riveted to the metal cap, and the latter to fit well and to be firmly soldered to the body of the case at both ends.

The condensers to be fully equal to pattern as regards workmanship and finish.

The case to be stove-enamelled with a finish equal to that of the pattern. The enamel to be hard but non-chipping.

National Telephone Company's Specification for Condensers (Technical Details only).

1. The capacity to be not less than 1·8 nor more than 2·2 microfarads when tested with direct current at 4 to 5 volts, and with an alter-

nating current (sinusoidal wave) at 4 to 5 volts and 800 periods per second.

2. The insulation resistance to be not less than 100 megohms between the two plates and between the plates and the case when tested with an E.M.F. of 100 to 200 volts.

3. The condensers to withstand an E.M.F. of 400 volts maximum (not R.M.S. value), alternating at 20 to 25 ∿ per second applied at the terminals for a period of half a minute.

FOILED PAPER CONDENSERS.

Temperature Coefficients for Correcting Insulation Resistance to Standard Temperature (60° Fahr.).

(400 Volts, 60 Seconds.)

Testing Temperature. Deg. Fahr.	To Correct to 60°, Multiply by	Testing Temperature. Deg. Fahr.	To Correct to 60°, Multiply by
50	0·710	71	1·457
51	0·734	72	1·508
52	0·759	73	1·561
53	0·785	74	1·616
54	0·812	75	1·673
55	0·840	76	1·732
56	0·870	77	1·793
57	0·901	78	1·855
58	0·933	79	1·919
59	0·966	80	1·986
60	1·000	81	2·055
61	1·035	82	2·127
62	1·071	83	2·202
63	1·109	84	2·279
64	1·148	85	2·358
65	1·188	86	2·440
66	1·229	87	2·525
67	1·272	88	2·613
68	1·316	89	2·704
69	1·361	90	2·799
70	1·408		

Discussion.

Sir John Gavey.

Sir John Gavey: I should like to make one brief remark in reference to the introduction of the rolled method at Mount Pleasant. This method was not of my design, as might be gathered from the paper. I owe it to a hint given me by my good friends the Western Electric Company, at New York and Chicago. The way in which Mr. Mansbridge moved onwards from that in use in America to that

designed by him, known as the foil-paper method, is very interesting, and the manner in which he overcame the difficulties of obtaining a well-conducting foil paper almost resembles a stroke of genius. The fact also that this new method involved a self-sealing condition which eliminated accidental faults is one of very great value. Many of us will remember in the olden days, when the plate lightning arrester was first introduced, these arresters certainly prevented damage to the instruments they were intended to protect, but they generally put the line to earth and caused an interruption of varying duration. This earthing of the line was due either to the carbonisation of the paraffin paper separating the earth and the line plates, or to the fusing of small particles of metal which placed them in contact. I must confess personally that when we first introduced condensers on a large scale in telegraph circuits for quadruplex and other methods of working I rather anticipated that we should get a good deal of the trouble that we had experienced with plate protectors, and I was ultimately glad to find that my fears were unfounded, because although in theory the condenser would represent a very extended lightning arrester, in practice it absorbed the charge without causing a disruptive discharge to earth. We must bear in mind, of course, that an ordinary lightning discharge from a telegraph circuit is, as a general rule, rather an inductive than a direct effect; in other words, when the pressure from a lightning cloud passing over a line of conductors is reduced by a flash of lightning the static stress in the telegraph wire is released, a discharge takes place, and when the end of the wire is connected with a condenser of about the same capacity as itself the discharge harmlessly divides itself between the wire and the condenser. The use of condensers, if I may be permitted briefly to refer to that aspect of the question, has increased marvellously in the telegraph and telephone service. I should not like to say how many millions of condensers are now in use. At all events, every telephone circuit fitted up on modern principles has a condenser in it. They have been largely used for telegraph purposes, and that use is extending day by day, so that I think it is not a very far-fetched idea if I say that we are within measurable distance of having a condenser on every telegraph circuit as we have on every up-to-date telephone circuit. The use of condensers has allowed us to introduce universal battery working on omnibus circuits which had previously to be supplied with independent batteries at every small station. This in itself will involve an enormous economy in telegraph working, and I think it is almost certain that the use of condensers will become universal on telegraph and telephone circuits within a brief period from now. From this point of view, therefore, anything which tends to facilitate their manufacture, to reduce their price, and to render them more stable is a very great advantage to both services. Sir John Gavey.

Mr. J. E. KINGSBURY: It may be interesting if I took a few moments in referring to one or two historical facts in connection with the use of condensers on telephone circuits and the methods of their manufacture. One of the earliest references to the use of condensers on Mr. Kingsbury.

Mr. Kingsbury.

telephone circuits that I have been able to find is in a patent which was deposited in the United States Patent Office by Black and Roseburgh on June 4, 1878, although it was not issued till February 18, 1879. It was for the use of a condenser in place of a type of apparatus which had been mentioned in a previous specification of Roseburgh's, and it is of interest to note that the type of apparatus which it displaced was practically the same thing as the tube which Mr. Mansbridge has explained to us is used in these high-tension condensers. This was the fourth claim of Roseburgh's U.S. patent, No. 212,510: "In telephony a glass tube (*a*) filled with glycerine and water or other suitable liquid, and provided with air-tight fitting caps (*b b*) connected with platinum points (*d d*) forming a high resistance medium capable of offering high resistance to the galvanic current and comparatively little resistance to the induced current, applied substantially as and for the purpose specified." That was issued on February 18, 1879, and filed on May 25, 1878. A few days later, apparently, he had found that a condenser was far more suitable for the purpose he had in view than the tube of glycerine and water, and the first claim of his second specification (No. 212,433) was: "At any station of a telegraph or telephone line, and on a derived line of the same, the combination of a telephone, with or without other secondary-current apparatus, and a condenser, so that the secondary-current apparatus may be used without interfering with the action of the galvanic circuit and so that the galvanic circuit may be broken between the points where the two ends of the derived line are attached without breaking the secondary-current circuit, substantially as set forth." There might have been some earlier patents, but that is amongst the earliest that I have been able to find. It may be of interest also to note that in that specification a condenser is described as follows: "The condenser is constructed of alternate layers of tinfoil and thin plates of mica, guttapercha, or paper saturated with paraffin, arranged like the leaves of an interleaved book. Each alternate metal plate is connected so as to form a distinct series, and each series is insulated from the other, one of which should in this case be connected with the line and the other with the earth, the telephone being inserted above or below the condenser as may be most convenient, but forming part of the same circuit." That description I think would apply to almost any condenser until about 1896. Condensers were used in telephone working to a small degree only and for very special purposes; no considerable demand had existed for them. But in 1896 the central battery system was being actively developed. The central battery system eliminated the magneto, and hence provided, other things being equal, a cheaper substation outfit. But the condenser of the period was a costly apparatus, difficult to make, and unobtainable in large quantities. I think we may say that the invention of a cheap and practical condenser was as much the invention of necessity as any other invention that we have to deal with. The American Bell Telephone Company found themselves in the position of requiring a cheap condenser, a small condenser, and

a condenser which could be manufactured in large quantities. The demand created the supply. There were three engineers in the employ of the Company, named Lee, Westcott, and Robes,* who tackled the problem and developed a condenser manufactured from rolls of paper and rolls of tinfoil, using machinery for the purpose, very much after the manner that Mr. Mansbridge has shown us in operation this evening. Their method, having been brought to a practical conclusion, supplied condensers for shillings instead of guineas, and permitted the manufacture by millions instead of tens. As Mr. Mansbridge has told us, that was the position of the art when he took a further step forward. It seems obvious that if a single sheet of paper can carry with it the metal there must be an economy; there ought to be greater certainty than in the case of running two separate strips of material, and it seems to me to indicate a very happy thought on the part of the author to bring about that combination. In practice I know there were some difficulties in carrying out the author's work as originally introduced, but I think it was that further happy thought of burning out the faults and applying an apparently destructive current to the substance that put into actual practical shape what before perhaps had something wanting. As between Mr. Mansbridge's condenser and the form previously in use, that is not a point upon which I am in a position to offer any criticism or make any comparisons. There would seem to be an obvious advantage in Mr. Mansbridge's form, and so much is that a matter of our belief that in our London factory we have adopted Mr. Mansbridge's process. If we have not been enabled to convince all other factories of its superiority, perhaps it is only a question of time before we are able to do so. Mr. Kingsbury.

Mr. A. WHALLEY: Representing one of the first firms which took up a licence under the author's patent, my experience has been only in making condensers in the rolled form of foiled paper, and having a single interleaving paper half a mil thick between the two foiled papers. Mr. Mansbridge's paper refers primarily to the use of condensers of his own pattern for telephonic and telegraphic work, but they are of some interest at the present moment, one might think, also to electric light engineers, especially as it was recently brought out in the discussion before the Institution on Messrs. Handcock and Dykes's paper on metallic filament lamps that the use for lamp circuits of transformers, or auto-transformers, seriously lowers the power factor of the lighting circuits. These condensers, with only a single interleaving paper, are quite suitable to use in capacities of 10 or more microfarads, and will stand all day long 230 volts with scarcely a noticeable rise of temperature, and could no doubt be made to stand from 450 to 500 volts; at any rate, it would be worth consideration as an attempt to raise the power factor at a comparatively small cost. As regards the breakdown point mentioned of 150,000 volts per centimetre for the metallic foil condensers, our own practice Mr. Whalley.

* Lee, Westcott, and Robes U.S. patent is No. 575,653. Filed July 8, 1896. Issued January 19, 1897.

Mr. Whalley

in the shops at Helsby is to strain these condensers with a direct current of 500 or 600 volts sent through a commutator to give a flat-top curve, alternatively positive and negative; we sort out the weak or defective condensers by that pressure and they stand it for a long length of time. The "degree of electrification" which Mr. Mansbridge mentions at page 557 as falling seriously with a rise of temperature is, as Mr. Mansbridge mentioned verbally to-night, the percentage fall of electrification. Apparently the temperature co-efficients which are given on the last page for correcting the megohms do not apply when correcting the percentage fall of electrification, but it is not quite clearly stated. Frequently the condenser shops are at high temperature, something like 85° F.; and it would be of interest if it could be brought out in the discussion whether temperature has also a serious effect, under the National Telephone Company's Specification, on the difference between the observed capacity measurement with direct current and with alternating current. The formulæ given on page 559 for measuring the megohms per microfarad of the condenser are interesting. They are, I presume, the maximum possible figures, and not the specification figures. Apparently they are based on something like 1,750 megohms per microfarad at 60 degrees at a pressure of 300 volts. The Post Office Specification gives a figure of 1,000 megohms per microfarad for telegraph condensers, and for telephone condensers about 300, so that different constants will be needed to get the specification figures. Artificial cables will be, I believe, of very great use to technical colleges if they lay themselves out to cultivate and spread a knowledge of the telephonic art, as Mr. Gill hopes, and they will soon be on the market at a reasonable price, up to sixty or more miles. The author's process has become the standard on the Continent, I believe, and in Great Britain, and possibly it will soon become the standard also in America.

Major O'Meara.

Major W. A. J. O'MEARA, C.M.G.: It may be of interest if I gave a few statistics as to the use of condensers in the Post Office. During 1906 there were issued for telephonic use 14,130 condensers, representing 32,200 microfarads; last year there were issued 14,800 condensers representing 33,550 microfarads. It may be of interest to know that at present we have in use on our telephone circuits some 80,000 condensers representing 0·18 farad. Sir John Gavey referred to the increasing use of condensers for telegraphic purposes, and I have a few figures in relation to that matter too. In 1906 we issued 2,130 condensers, representing 15,270 microfarads; last year we issued 2,470 condensers representing 12,130 microfarads. I am sorry to say I have not the exact figures relating to the total number of condensers in use on telegraphic circuits, but I understand that we have in this country 6,000 condensers.

I may say the figures I have mentioned refer to paper condensers manufactured as described by Mr. Mansbridge. We have had these condensers in use now for seven years, and I think I can support Mr. Mansbridge in his claim that they are satisfactory from every

point of view; that is to say, we have not found them to fail from loss of insulation or in any other way. Major O'Meara.

Mr. B. S. COHEN: There is one important point that Mr. Mansbridge does not refer to in his interesting paper, and that is the effect of alternating current on condenser capacity. It will be seen that, in the National Telephone Company's Specification for condensers, a reference is made in the first clause to a test with both alternating current and with the ordinary discharge method. Many forms of commercial condensers possess considerable dielectric losses, which result in a reduction in capacity, when measured by alternating current, to such an extent as to cause serious trouble. The necessity for testing condensers in practice with alternating current was, I think, first pointed out by the Engineering Staff of the Western Electric Company. A few years ago an investigation was carried out in the National Telephone Company's laboratories to determine the capacities of various types of commercial condensers at telephonic speech frequencies, and perhaps a few of the results may prove of interest. A batch of condensers of one pattern, with a mean discharge capacity of 2·09 microfarads, when measured by alternating current of 800 ∿, had a mean capacity of 1·76, or a percentage variation of 18·8. Another batch, when measured by discharge, had a percentage increase of capacity amounting to just under 1 per cent.; a further batch with an alternating-current capacity of 1·81 microfarads had a discharge capacity of 2·43, or 34·2 per cent. increase. One condenser tested had actually an alternating-current capacity of 0·6 microfarad, and a discharge capacity of 1·88 microfarad. From these figures it will be seen that the variation may be considerable, and, despite the fact that these condensers might have been accepted as satisfactory under a specification which only covered discharge capacity, insulation, and breakdown tests, many of them would give very serious trouble when installed in telephone instruments or circuits. Only a few condensers of the Mansbridge type have been tested and these do not show any great variations, though those made by the G.P.O. were apparently superior to those made by outside firms. It would not appear that, provided the foil is of negligible resistance, this type of condenser should vary more than the ordinary pattern. I might mention that, given an alternating current of about 800-∿ frequency, the workshop capacity test on condensers with this current is, if anything, simpler than the corresponding direct-current test, as all that is required is a standard condenser, slide-wire bridge, and a telephone receiver. The question of insulation-resistance variation of commercial condensers with alternating current does not appear to have been studied to any very great extent, and I should like to ask the author if he can give us any information on that subject. The tests for this, involving as they do measurements of very small power factors, are more difficult to make commercially than the corresponding capacity tests, which, I think, in all probability cover the effects. In this connection I should Mr. Cohen.

Mr. Cohen. like to refer to the artificial cables for telephone work that were mentioned by Mr. Mansbridge and also by Mr. Whalley as being shortly ready for the market. Whilst probably of great use for educational work, I should think it very possible that such cables might introduce some dangers in use. The general type of artificial cables manufactured for actual telephone work have the capacity and resistance lumped to such an extent that the result is the same as if they were evenly distributed within a very small percentage. Such artificial cables, if manufactured with silvered mica condensers, act almost in the same manner as telephone dry-core cable, as the latter shows very little variation in capacity with alternating current. If artificial cables, however, are manufactured with capacities made up with paraffined paper, care would have to be taken to avoid trouble caused by variations in capacity.

Mr. Oppenheimer. Mr. H. OPPENHEIMER: As far as I am concerned, I can congratulate Mr. Mansbridge on the progress he has made since I first saw his apparatus, two years ago. There is no doubt that to-day the manufacture of the telephone condensers is merely a matter of practice. The elementary stages have been solved by Mr. Mansbridge, and those firms which have taken up the manufacture have been initiated in such a perfect manner that even at the very start the relative results are very satisfactory. I remember that from the first batch of condensers we made we had about 7 per cent. "wasters"; in the second lot we brought the figure down to 3·8, in the third batch to 1·6, the next to 0·36, and to-day we have arrived at 0·2. It is remarkable when one compares the various specifications to see how the telephone departments who have most common battery experience have come practically to the same conclusion, and have fixed the tests almost alike. As far as the pressure to be applied is concerned, I think the G.P.O. Specification prescribes 300 volts, the National Telephone Company 400 volts, the Colonies 1,000 volts, and the Continent 350 volts. The time during which the test is applied is, in the G.P.O. two minutes, the National Telephone Company half a minute, the Colonies five minutes, and the Continent one minute. The insulating resistance is, in the G.P.O. 300 megohms, the National Telephone Company 200 megohms, the Colonies 1,000 megohms, and the Continent 400 megohms. These figures appear to show that, although the Colonies are at the present moment endeavouring to take advantage of the experience gained on this side and to introduce common battery working, still they are placing certain restrictions round the attributes and devices used in connection therewith which are certainly detrimental to progress. To require that an ordinary telephone condenser should withstand a 1,000-volt pressure for five minutes and that its insulation resistance should be 1,000 megohms is practically nullifying the efforts and the progress made by Mr. Mansbridge.

Mr. Taylor. Mr. J. E. TAYLOR: In connection with high-tension condensers of the silvered Leyden jar type to which Mr. Mansbridge refers in the earlier part of his paper, I have had some experience with these for

wireless telegraphy purposes which may be of interest. Some years ago, before the Moscicki condensers were put on the market, I had several experimental Leyden jars made with coatings of chemically deposited silver, and though they had some advantages over the usual tinfoil-coated jars, particularly as regards efficiency in producing electrical oscillations, they also had some serious drawbacks. The silver coating was very easily damaged, either mechanically or electrically, in the latter case by an effect very similar to that producing the "self-sealing" quality in the Mansbridge foiled paper condenser. It was found difficult to make secure connections to the silver coatings of such a nature that no sparking occurred at any point of connection, and so soon as the minutest trace of sparking occurred the silver was rapidly eaten away. In other cases accidental sparking to neighbouring wires or other conductors produced the same effect, which, if unobserved, quickly caused erosion of considerable areas of the coatings. Backings of electro-deposited copper and of celluloid varnish were tried but did not prove altogether satisfactory. The copper coating on the curved surfaces of a Leyden jar is liable to become detached and peel off, while the varnishes do not afford complete protection from the sparking trouble. A similar erosion also occurred at the upper edges of the coatings due to the well-known "brush" discharges which take place there. In connection with these brush discharges from Leyden jars which are a source of damping losses in the oscillating circuit of a wireless telegraph transmitter, I do not remember to have seen a really satisfactory explanation of their cause; the usual explanations based upon the surging of the charges round the circuit or the decrease of specific inductive capacity of glass at high frequencies of alteration are not adequate. The matter, it seems to me, is best explained as an effect of ionisation of the air at the edges of the coatings. Successive oscillations during the period of discharge build up the ionisation which facilitates and augments the discharges primarily due to the density of the electric field at the edges. This will account for various effects observed, notably that the more sustained the oscillations the more pronounced do the brush discharges become. This view also fits some of the effects noticeable in improperly adjusted spark gaps in wireless transmitters when the conditions are such that the first rush does not create a spark, but perhaps causes a brushing or spitting discharge which, after a fraction of a second, ionises the air sufficiently to facilitate the formation of the main spark, weakened, however, to an abnormal extent by the energy absorbed in the first part of the process. Mr. Taylor.

Reverting to the Mansbridge foiled paper condenser, I can support some of the advantages claimed for the self-sealing quality of these appliances. I have found it possible to make efficient and satisfactory use of them for spark-suppression in a circuit containing a strongly energised electromagnet where a condenser of the older type and having the same capacity would not stand a single rupture of the circuit. With the Mansbridge condenser there is less chance of perforation of the

Mr. Taylor. dielectric, and when it does occur it does not perceptibly impair the condenser. Indeed, there is no doubt that a very large number of these perforations must take place before the condenser is rendered useless. Its replacement then would not be a matter of serious expense in view of the cheapened process of production.

Dr. Silvanus Thompson. Dr. SILVANUS P. THOMPSON: I have nothing to say beyond expressing in common with all of us, the admiration we have for Mr. Mansbridge's work. But as I am ignorant on the subject of the modern condenser, I feel disposed to ask two questions. In the first place, we saw a strip exposed to the test flashing with sparks as all the faults in the paper and at its edges were discovered by the machine and burnt out. I want to know what will happen if that paper is sent through a second time. Will it flash at all, or will it flash much or little? Does the flash successfully burn out all the faults or find some more a second time over? The other question is this: It was an exceedingly interesting physical fact to be told that the metal-deposited paper before being calendered was almost a perfect non-conductor. I want to know whether it, in common with other metallic films that are made of bad-conductivity materials, becomes a better conductor in the presence of electric oscillations; in fact, would a strip of that uncalendered paper act as a coherer and become as a conductor? I have been making some private inquiries of my friends sitting near me of how much a microfarad costs nowadays. I am the possessor of various microfarads, and the dearest condenser I ever bought—it was only one-third of a microfarad—I paid two and a half guineas for. At that rate a whole farad would have cost about £7,870,000, but I fancy nowadays a farad could be bought for something like £50,000.

Mr. Mordey. Mr. W. M. MORDEY: The author has clearly made an important advance in the construction of condensers. I wish to ask some questions directed particularly to an aspect of the subject on which I once tried to do some work. I refer to energy loss in dielectrics. Some years ago I read a paper* here on dielectric losses in cables. I was unfortunate enough to make my experiments on a rubber cable which had the exceptionally high power factor of something like 0·1, and I was led to draw certain general conclusions as to losses in cables due to this cause—conclusions which were much too high for cables such as are now generally used. But on going into it later I found that the dielectric hysteresis loss, in even the best cables that can be obtained, is so high that under certain conditions it may cause more waste of energy than the current through the copper. It would be very interesting if the author, who evidently has exceptional facilities, could go into the question of the losses in dielectrics. With regard to the Moscicki high-tension condenser shown by the author, it would be easy to test that, as it seems to be provided with a water circulation which might be intended for the very purpose of determining the losses by measuring the amount and rise of temperature of the water. I should

* "Capacity in Alternate Current Working" read Jan. 10, 1901 (*Journal Institution of Electrical Engineers*, vol. 30, p. 364).

not expect to find a lower power factor than 0·03. At that power factor the loss at 50 ∿ and 1,000 volts would be 10 watts per microfarad, at 10,000 volts the loss would be 1,000 watts, and so on. Such losses may affect the question of the use of condensers on power circuits; in any case it would be well to know what they are. Some time ago I tried to get some idea of how that loss was caused, and I made the suggestion that the mere static attraction between the electrified surfaces, being often repeated as it is with alternate currents, is in itself sufficient to account for a good deal of what we call the dielectric hysteresis heat loss. It may be largely mechanical. For example, if my arithmetic is not wrong, with a 20,000-volt condenser or cable and a dielectric 0·2 inch thick, the static attraction is about 2 lbs. per square foot. This repeated 100 times a second on any dielectric may account for a good deal of heat. Applying that idea to the interesting example the author gives and illustrates in connection with Fig 6, of the breakdown of a condenser at 1,200 volts, assuming that the thickness of the dielectric is about 0·001 inch (which I think from an earlier part of the paper is right), the actual pressure between the metallic films in this condenser due to electrostatic attraction may be about 200 lbs. per square foot or 1·4 lb. per square inch. True, the attraction may be to a certain extent balanced at the two sides of a film of a condenser, but where it is not balanced the pressure alone may be quite large enough to account for a breakdown. Mr. Mordey

The PRESIDENT: During the war in South Africa we, the Corps of Electrical Engineers, used the Swedish cavalry pattern telephones which contained condensers, and that this outfit enabled us to do exceptionally good service by enabling speech to be carried on through fine wire uninsulated metallic circuits laid from bicycles on the bare Veldt, and that the condenser attachment was, I believe, the cause of our being able to make ourselves heard and understood even if these circuits were broken by cattle or other means tearing them apart; in several instances we obtained audible speech although the gaps must have been many feet in length, and we know that we could signal buzz-messages through many yards of such breaks. This fact was of national importance, as at a time when the telegraph service had been destroyed we maintained communications and hence were able to relieve a good deal of anxiety at home while the telegraph lines were being repaired, as these telephone communications were the only connection between the Army in front and Capetown. The President.

Dr. ALEXANDER RUSSELL (*communicated*): The paper is of special interest to me as the data given throw light on some curious phenomena in connection with the use of condensers in laboratory work which I have noticed. It follows from Kelvin's criterion for an oscillatory discharge that when the resistance of the ballistic galvanometer used to measure the discharge of a condenser is sufficiently small the discharge will be oscillatory. In this case we would expect that the galvanometer would act in a curious way. When investigating these effects I discovered that certain needle galvanometers had "dead Dr. Russell

Dr. Russell.

points" for transient currents. I have found, for example, with those galvanometers that if the needle be at a "dead point" it will remain stationary however great the discharge that passes through the galvanometer coil. If we diminish the resistance in series with the condenser, we get a large throw in one direction, but if we increase it we get a throw in the other direction.* In some positions of the needle the throws on charge and discharge are in the same direction, whilst in others they are in opposite directions. The phenomena, although fairly complicated, can be explained easily and satisfactorily if we assume that an ordinary condenser acts like an ideal condenser with a non-inductive resistance of a few ohms in series with it. So pronounced is this effect that I find it useful to classify condensers according to the magnitude of this "effective" internal resistance. In some condensers this effective resistance is large, and they are not suitable either for measuring inductance in terms of capacity and resistance, or for producing Duddell currents. Probably those unknown causes which are generally classified under dielectric hysteresis and absorption have something to do with this effect, but I have always held that it is mainly due to the resistance of the sheets of foil used in making the condenser, and a perusal of this paper confirms me in this opinion. I think that if efforts were made to have the conductivity of the foil as great as possible a thoroughly satisfactory condenser suitable for measurements with high-frequency currents could be produced.

The effect of the resistance of the foil can be discussed mathematically. To simplify the theory let us consider a condenser made up of two long strips of foil having terminals at their ends, and separated by a dielectric of high insulativity and in which the absorptive effects are negligible.

Electricians customarily assume that the formula to give the capacity K in farads, when the voltage is sine-shaped, is $K = A/\omega V$, where V and A are the effective values of the voltage and current respectively, and ω is 2π times the frequency. The true formula for this case may be shown to be †—

$$\frac{A}{\omega V} = \sqrt{\frac{K}{\omega R}} \left[\frac{\cosh y - \cos y}{\cosh y + \cos y}\right]^{\frac{1}{2}},$$

where $y = \sqrt{2\omega K R}$, and R is the resistance of the two strips of foil in series.

Provided that y be not greater than unity, that is, provided that $2\omega K R$ be not greater than unity, we may write with high accuracy—

$$\frac{A}{\omega V} = K\left(1 - \frac{7}{90}\omega^2 K^2 R^2\right).$$

If we had a non-inductive resistance R_1 in series with an ideal condenser K the corresponding formula would be—

* *Phil. Mag.* [6], vol. 12, p. 202, 1906.

† Russell, "Alternating Currents," vol. 2, p. 471 (48).

Dr. Russell.

$$\frac{A}{\omega V} = \frac{K}{(1 + \omega^2 K^2 R_1^2)^{\frac{1}{2}}}$$

$$= K\left(1 - \frac{1}{2}\omega^2 K^2 R_1^2\right),$$

approximately, when ω K R_1 is small. If we assume that $R_1 = (7/45)^{\frac{1}{2}}$ R the formulæ become identical. Now, the smaller the resistance in a circuit the more nearly does the oscillatory discharge current assume its limiting form of a sine-shaped alternating current. Hence the mere fact that the capacity of condensers must be regarded as distributed capacity suffices to explain some of the phenomena observed in practice. It also points out a serious limitation to the use of condensers with high-frequency alternating or pulsating current for testing purposes, when the highest accuracy is desired.

Mr. A. W. Ashton. Mr. Ashton.

Mr. A. W. Ashton (*communicated*): Though the method of specifying insulation resistance as the ratio of the testing voltage to the current entering the condenser after one minute's electrification is convenient in practice, yet the figure so obtained is certainly not a resistance. The current from which the true resistance of a dielectric may be calculated should represent energy converted into heat in the dielectric, which energy is not recoverable on discharge. From experiments which I have made on foil-paper condensers I have found that the current entering the condenser after charging has been continued for 72 hours is only about 5 per cent. of the current at one minute's electrification: also after charging for a long period the curve of discharge current becomes approximately the same as the curve of charging current. This is very important, and shows that nearly the whole of the quantity entering the condenser during electrification represents recoverable energy. Since the difference between the energy absorbed and that given out represents the amount converted into heat, it is evident that this latter must be very minute and the true resistance of the dielectric very high. I have shown elsewhere (see *Phil. Mag.*, November, 1901) that for certain dielectrics the current representing the absorbed energy may be represented by an expression of the form $K t^{-x}$ where K = a constant, t = time since commencement of charge, and the exponent x varies from 0·43 to 0·78. With foil-paper condensers I have found that this law is only approximately true, and the exponent of t varies from 0·53 to 0·58. The author's equations on page 559 confirm this figure, as the exponent of the time in these equations is 0·5.

With regard to the discrepancy noticed by Mr. Cohen between the values of the capacity as measured by alternating and direct currents, there is no doubt that the quantity discharged from the condenser is a function of the time of *discharge*. The capacity calculated from a discharge lasting, say, $_{10}{}^{1}{}_{00}$ sec. must differ considerably from that determined by means of a ballistic galvanometer. In fact, if it were possible to use a galvanometer which would integrate the discharge

Mr. Ashton. for the first ten minutes the capacity so determined would be nearly doubled.

Dr. Sumpner. Dr. W. E. SUMPNER (*communicated*): There is no doubt that the applications of condensers to power installations using alternating currents would be both numerous and important if the condensers could be made sufficiently small, cheap, and safe. In each of these three respects the Mansbridge mode of manufacture is a decided step in advance, but I should like to emphasise the matter of safety. The author, having in view mainly applications to telegraphy and telephony, has, I think, not sufficiently dwelt on the question of safety. The self-sealing property of these condensers is closely analogous to that of oil insulation for high-tension transformers and switches. Hitherto condensers for power purposes have been mainly of the electrolytic type, and their high power factor and sloppy character render them unsuited for engineering purposes. Other condensers have been liable to breakdowns causing serious short circuits. But the condensers now described act as automatic cut-outs if from any cause they break down. The high resistance of the metal films prevents serious currents passing, and the breakdown current merely causes a rupture of the electrical connections. In this respect these condensers seem safer than choking coils, for if a fault develops in the latter a serious short usually occurs. During the last two years I have largely used these condensers for voltmeters and phasemeters of the type recently described by Mr. Record and myself. We have already pointed out that one of these instruments is admirably adapted to the rapid measurement of the true capacity of such condensers. But the point I wish to make is the fact that during a large amount of testing spread over two years there has been no case of a short circuit due to the subjection of such condensers to alternating voltages (I have not used pressures above 400 volts). Several cases have occurred in which the capacity has considerably fallen off. But these cases can fairly be attributed to faulty manufacture resulting in the formation of cracks in the thin metal film, such cracks ultimately becoming ruptures under the action of the current. The better condensers, sorted after subjecting them to alternating voltages for several hours, have in no case, so far as I have been able to detect, altered their capacity in the slightest degree owing to the action of alternating current, even when frequently used with such currents over a period of eighteen months.

Some of the time-honoured modes of testing and specifying the properties of condensers need revising now that Thomson galvanometers and electrometers are no longer the only, or the best, instruments for making condenser measurements. The three important properties of a condenser are its capacity, its insulation resistance, and its power factor. The phrase "megohms per microfarad" may be usual, but is both a clumsy and inaccurate term for its time-constant in seconds. The capacity can now be quickly tested by a non-reflecting instrument. The insulation can as easily be tested by permanent magnet voltmeters and micro-ammeters. The power factor is more difficult to measure, but is

Dr Sumpner.

the best and least fanciful way of summing up the absorption properties of the condenser. I should like to draw attention to a very useful paper on condensers by F. W. Grover,* who has tested a large number of mica and paraffin-paper condensers obtained from various makers in Europe and America. The results are of interest. The alternating current through a condenser differs from exact quadrature with the volts by a small angle θ such that $\sin\theta$ is the power factor. Out of 54 mica condensers of various makes the value of θ for 18 (or one-third of these) varied from half a minute to 3½ minutes. For 36 of the condensers (or two-thirds) θ was less than 17 minutes, and for 11 out of the other 18, θ was less than one degree. The remaining 7 condensers were bad. This means that the power factor for 47 out of the 54 mica condensers was less than 0·0175, for two-thirds it was less than 0·005, for one-third it was less than 0·0011, while in one case the power-factor was so low as 0·0002. Similarly out of 20 paraffin-paper condensers of various makes the power factor for two-thirds was less than 0·02, and for one-third less than 0·006, while the lowest was 0·0017.

Some of these results may need confirmation, for Mr. Grover's methods of test were most complicated and laborious, and few experimental details are given. But there can be little doubt about the diversity of the results. The various values for the power factor can hardly be attributed to differences in the dielectric; they are much more likely to be due to the conducting surfaces. The loss of power due to the resistances, or to minute arcs, in such surfaces is probably the most serious part of the condenser loss. The views that have been advanced about dielectric hysteresis appear to me to be purely imaginary. In any case the power-factor of reasonably well made condensers is so low that the loss of power is negligible for engineering purposes. Size, price, and safety are the only important matters.

Mr. Stubbs.

Mr. A. J. STUBBS (*communicated*): I am disposed to think that the "breaking down" effect is probably due to the presence of metal-filled perforations rather than to sparking over simple air-gaps and subsequent fusion of the surrounding metal, but it is likely that an observer of Mr. Mansbridge's calibre will be able to remove one's doubts about his theory.

He himself, however, seems to think that breakdown of the more robust type of metal-foil condenser must be accounted for on somewhat different lines. Of course, the use of two thicknesses of paper instead of a single piece of double thickness is a precaution against the occurrence of flaws in manufacture, but breakdown with two thicknesses cannot be attributed to a flaw in each coinciding. I think that perhaps the idea of the presence of *conducting* flaws in the paper may be strengthened by recent experience with our paper-insulated cable. In one case a whole delivery from the paper mills was found after manufacture of a considerable length of cable to contain conducting particles which, in favourable circumstances, broke down the insulation of the cable.

* Washington Bureau of Standards, vol. iii. No. 3.

Mr. Stubbs. "Megohms per microfarad" like "Megohms per mile" seems too expressive a term for the practical man easily to give up in favour of the somewhat more correct "Megohm-microfarad."

In regard to the melting or setting point of paraffin wax, I do not understand Mr. Mansbridge to mean that in practice his normal test takes thirty minutes? An equally satisfactory and much speedier method is to place a small tube partly filled with wax against a thermometer and heat the two in water, observing the temperature when the wax begins to rise in the tube. The longer method is certainly interesting, but is—as is implied in the paper—not that used to obtain the (probably equally accurate) melting points specified by the dealers.

The great variation of insulation per degree of temperature, if unquestionable, certainly makes one glad that the question of insulation is not of prime importance. It would be interesting to know, however, if the tests made were absolutely conclusive.

Mr. Mansbridge's work has been an important factor in the extension of the now almost universal adoption of common battery working, and it may perhaps be news to him to hear that condensers may prove at no distant date the salvation of the telephone system itself! Recent experience shows that the telephone acts as a sort of spark-gap for the oscillatory currents of radio-telegraphy, resulting in the breakdown of the telephone. With cheap condensers the telephone engineer may view the installation of a wireless station by the Admiralty in the heart of London with comparative complacency when he knows that the 5 farads which according to Mr. Mansbridge can be manufactured in a year would suffice to protect a hundred million telephone circuits from this latest and most insidious enemy, as a condenser of only 0·05 microfarads put across the circuit is found to prevent sparking. It is possible even that the capacity of the leads will prove to give sufficient protection.

Mr. Addenbrooke. G. L. ADDENBROOKE (*communicated*): Some recent work of mine on the behaviour of dielectrics under high alternating stresses bears on points dealt with in Mr. Mansbridge's interesting paper.

For convenience of experiment some of my work has been done with condensers having tinfoil electrodes, and I have come across and employed the interesting self-sealing property to which Mr. Mansbridge alludes. It was convenient chiefly because in breaking down insulation its use prevented such serious arcs as when solid metal plates are employed. Mr. Mansbridge is much to be congratulated on his practical application of this property.

Mr. Mansbridge's work does not appear to have led him, so far, seriously to consider the losses in the dielectric when submitted to alternating pressures over considerable periods and the heating which then occurs, which, as well as the cost of manufacture, has been the chief deterrent to the use of condensers hitherto in connection with the transmission and use of alternating currents for power supply; but an intelligent commencement of manufacture having been made, we may undoubtedly look for developments in this direction. It will,

however, be a condition that such condensers must have small dielectric losses. Mr. Addenbrooke.

For some time I have been impressed with the value of measuring the losses in dielectrics, not only for their importance in themselves, but because so much other information regarding the behaviour of the dielectric under different conditions can be obtained in this way. The initial difficulty has been, however, to find a satisfactory way of measuring these losses, as has already been mentioned. I have accordingly devoted a good deal of time to working out a method of measurement applicable to small capacities or short lengths of cable. As a result I am glad to say that by the use of the electrostatic wattmeter which I brought out some time since, with certain modifications, it is possible to measure the losses in capacities as small as $\frac{1}{1000}$th. of a microfarad and at any voltage which may be required from, say, 500 volts upwards and at very low power factors. With this apparatus I have been able to secure some interesting results which I hope to make public shortly. One or two points, however, may be mentioned. There are, as has already been hinted in the discussion, great differences in the losses which occur in condensers and cables, depending on their construction. For instance, in a paper condenser kindly lent to me by Dr. Muirhead the loss is as low as $\frac{1}{4}$ of 1 per cent of the apparent loss, which means a loss of about 3·5 watts in a 1-microfarad condenser submitted to an alternating current of 83 periods and 1000 volts. This is the best result I have come across so far, but in most cases the losses are much larger and with bad construction may amount to 30 per cent to 40 per cent. It must be borne in mind also that the charge of the condenser depends on the shape of the alternating wave, and with a high peak the current flowing in and out of the condenser is larger than would be deduced from the voltmeter reading which reads the root of mean square of the volts. Consequently the capacity appears higher. In fact, a measurement of the current flowing into a condenser of a known capacity at a certain voltage as measured by the voltmeter may be used as a rough indication of the shape of the alternating wave. It may be that some of the discrepancies in Mr. Cohen's results can be accounted for in this way.

Mr. J. W. Record (*communicated*): I am inclined to take exception to the word "foiled paper," which Mr. Mansbridge uses throughout his paper to distinguish the new type from those containing tinfoil plates. The word "foiled" is not sufficiently comprehensive, and is likely to cause confusion, and as the paper is actually painted, or coated with a metallic film, the word "coated" paper would be more applicable for the metallic painted type and "tinfoil" condensers for the foil plate pattern. Mr. Record.

Condensers with coated plates are to be recommended for the ease with which they can be wound, and for the reduction in the weight of material. I am not, however, in entire agreement with Mr. Mansbridge regarding the pressure to be applied to a particular plate. With a tinfoil condenser the foil, being laid on separately, cannot be in such perfect

Mr. Record. cohesion with the dielectric as is the case with the coated paper, therefore an increase of pressure in the former will have far more effect than in the latter. Mr. Mansbridge prefers to leave the pressure applied to a plate to the discretion of the operator, rather than to work to gauges. Personally I prefer to eliminate the human element as far as possible, and from the above considerations it will be seen that if a small variation in pressure does result, the capacity will not be materially affected. Moreover when working to gauges a far lower rated operator can be employed on the work.

I have measured the resistance of a 2-microfarad condenser of the "coated" type, containing 50 ft. per plate 3½ in. wide, and find it to be about 90 ohms. A similar length of "tinfoil" paper has a resistance of 3·75 ohms. This question of resistance is of great importance when the condensers are required for the suppression of sparks on high-speed tremblers, such as induction coils, and I have found that a coated paper condenser must either have several contacts on each plate for reducing its resistance, or else a condenser of larger capacity than would be necessary in the tinfoil type must be used. This brings us to a point of vital importance, both with regard to the testing and specifying of condensers. Evidently the National Telephone Company are alive to this fact, as their latest specification provides for a test approaching working conditions.

The continuity of a coated condenser may be impaired through imperfect painting or creases at the folds, and the test employed should thoroughly search for these faults. This cannot be done with a continuous current test, for provided the circuit of the plate is not altogether broken the condenser will receive its full charge.

By far the most satisfactory means of measuring capacity known to me has been devised by Dr. Sumpner, and is described in a paper by Dr. Sumpner and myself, recently read before the Institution.*

Comparing the condenser current during test by the National Telephone Company's method with the alternating-current voltmeter method, referred to in that paper, and neglecting the resistance of the plate, we have—

$$C = E \not{p} k = 0{\cdot}0503 \text{ ampere}$$

in the former, and 0·125 ampere in the latter case, or 2½ times as much (100 volts and 100 ∿).

The alternating current voltmeter method enables a far more searching voltage to be applied during the test and a frequency that can be obtained without ordering a special alternator, and gives a current that will effectually burn out weak portions of the plate due to creases and other causes.

If the condenser is leaky, whether intentionally or not, true capacity is still registered on the instrument, because the leakage current, being in phase with the voltage, is nearly 90° out of phase with the

* *Journal of the Institution of Electrical Engineers*, vol. 41, p. 227, 1908.

moving coil current, and can have no effect on the deflection of the pointer. The method is one of comparison with a standard condenser, and the formula is similar to the ballistic galvanometer formula and is explained fully in the paper referred to above. Mr. Record.

The tests below were made on some 2-microfarad coated paper condensers. It is noticeable that in all cases the alternating-current voltmeter method shows a lower capacity than the ballistic galvanometer test.

Condenser No.	Insulation Resistance in Meghoms.	Ballistic Galvanometer.	Alternating Current, 100 Volts, 50 Cycles.
1	300	2·00	1·980
2	400	1·90	1·860
3	300	1·85	1·820
4	300	2·15	2·100
5	300	2·00	1·975
6	400	2·30	2·280
7	450	2·00	1·950
8	500	2·00	2·040
9	500	2·00	1·960
10	500	1·80	1·770

Mr. G. F. MANSBRIDGE (*in reply*): I have first to thank the various speakers for their interesting comments on the paper. Mr. Mansbridge.

Mr. Whalley raised the point as to the use of these cheap condensers for improving the power factor on distributing networks containing many small house transformers. I think that is a very happy suggestion, and I presume it is intended that the consumer who pays for the transformer should pay for the condenser. Then the question was raised as to whether the formula on page 559 is applicable to electrification. The answer is that it deals with megohms only. The variation of electrification with temperature is a problem which up to the present I have not had an opportunity of minutely scrutinising. These formulæ are based upon average results obtained with first-class manufacture, but the Post Office specification figures allow a considerable margin below.

With regard to Mr. Cohen's remarks, I had intended to deal with the alternating-current problem in my paper, but Mr. Cohen was kind enough to say some time ago that he intended to discuss the paper, and knowing how much attention he had given to this side of the subject, I purposely left the matter open, hoping to hear from Mr. Cohen the answer to the question he has now raised. At the Post Office factory we have tried alternating current in comparison with direct current, and although it seems rather like an advertisement, I must say that we have found that our condensers are so good that the difference between the results obtained with alternating and with

Mr. Mansbridge.

direct current is so small as to be scarcely measurable. I should point out, however, that our conditions are somewhat exceptional, inasmuch as we make practically the whole of our condensers, whereas Mr. Cohen has, I think, to deal with quite a number of manufacturers, of whom few, if any, have had the advantage of that long experience of condenser manufacture which has fallen to the lot of the Post Office factory.

With regard to the relative advantages of alternating and continuous-current tests for condensers, I should like to clear up a detail upon which there may be some misconception. Mr. Cohen points out that a defective condenser may have with alternating current an effective capacity which is only a fraction of its normal capacity, and he remarks that this defect is not shown up by the discharge capacity and insulation tests as taken by continuous current. This statement is perfectly true so far as it goes, but one important point has, I fear, been overlooked, namely, that the insulation test with direct current as ordinarily taken gives not merely a measure of the insulation, but a measure of the electrification as well, and it is by its electrification that a condenser shows its quality even more than by its insulation *qua* insulation.

In my experience the defect of low effective capacity with alternating currents is invariably shown up under the direct-current test by the failure of the condenser to electrify properly; that is to say, the deflection, instead of decreasing in proportion to the square root of the time as it should do, will decrease to a much less extent, or will indeed "open up"—that is, will increase rather than decrease. I should like, therefore, to emphasise very strongly the importance of the electrification stipulation in a condenser specification.

One point of warning with respect to tests with alternating current might here be mentioned. When using the slide wire, telephone receiver, and standard condenser referred to by Mr. Cohen, it may be found that no sharp dead-point is obtainable on the slide wire. The reason is fairly obvious, namely, that the phase relation of the currents in the two condensers is disturbed by one having a higher conductor resistance than the other. The standard condenser is usually made from sheets of tinfoil bunched together, and not by the rolling process; consequently the joint conductor resistance of the electrodes is extremely small, whereas with rolled condensers, particularly those of the coated paper type, the resistance of the strip may be a matter of several ohms.

In such a case it is necessary to insert a resistance in the standard condenser circuit before a good balance can be obtained, but the most satisfactory plan is carefully to standardise a rolled condenser and then to employ the latter as a sub-standard. By this means it is easy to get a dead sharp balancing position.

With regard to the variation in the capacity of artificial cables manufactured from coated paper, I would say that so far no difficulty has been experienced in this direction, but it is fair to say that the first cables so made are barely three years old.

With respect to the measurement of very small power factors, I

Mr. Mansbridge.

would say that in addition to the pamphlet referred to by Dr. Sumpner, another publication from the same office, but of rather later date, written by Professor Edward B. Rosa and entitled "Wattmeter Methods of Measuring Power expended on Condensers and Circuits of Low Power Factor," is of considerable interest and value in this connection. Copies of this pamphlet bearing the serial number 18, and also of the one by Mr. F. W. Grover, numbered 64, can doubtless be obtained on application to the Bureau of Standards, Washington, D.C. By the courtesy of Professor Rosa I have had the privilege of examining the apparatus used for these tests, and have nothing but admiration for the beauty of the methods and for the concordant results obtained.

With regard to Dr. Thompson's inquiry as to what happens if the coated paper is put through the break-down machine a second time, I have to say that this partly depends upon the voltage employed. If this is low, say 50 or 100 volts, there is practically no sparking at the second time of asking, but if higher pressures are employed, say 200 volts and over, the strain approaches the critical point of breakdown of the normal dielectric, and a certain amount of sparking is bound to occur each time that the paper is drawn over the rollers. I have not, however, been able to find any advantage in running the paper through the break-down machine more than once. My view of what takes place is that the defects which are burnt out the first time are the serious faults such as would be occasioned by the tin mud penetrating wholly or partly through the paper at a pinhole or a weak place in the body paper, or by a grain of metal, large as compared with the particles of tin powder, being driven into or through the paper in burnishing.

With regard to the uncalendered paper acting as a coherer, I cannot say for certain, but I am extremely doubtful, whether it could be made to act in the way suggested, but a strip of calendered paper, which has been so sharply creased as to become practically a non-conductor, can be made to act as a coherer.

With respect to Mr. Mordey's remarks concerning the Moscicki condenser, some results on the lines indicated will probably be made public very shortly, as I understand that a paper on the subject is to be submitted to the Institution. There would seem to be a good deal of truth in Mr. Mordey's suggestion that the dielectric loss may be partly mechanical and may be due to the oft-repeated blows on the dielectric. In those cases where the layers of dielectric have not been solidly cemented together there is no question but that the loss is partly mechanical, as the condenser can be heard and felt to be in vibration, and if the current is of high frequency a loud and distinct note will be produced by such an ill-made condenser. This emphasises the necessity already alluded to for so pressing and cooling the condensers that sufficient wax is retained in the plate. A properly constructed condenser of flat form if sharply struck should "ring" like a piece of dry mahogany, and I think it will be found that the dielectric losses in such a condenser, other things being equal, will be markedly less than in one giving a dull, lifeless sound when struck.

Mr. Mansbridge.

It seems doubtful, however, whether the whole of the losses can be accounted for by the "blows" referred to by Mr. Mordey; indeed, the word seems scarcely applicable in the case of a well-made condenser in which the dielectric possesses a fair amount of elasticity. On the other hand, I cannot agree with the suggestion made later in the discussion that the whole of the loss is due to the resistance of the metallic foils or coated strips. If, as suggested, any minute arcing occurs, the effect must necessarily be transient. It seems to me that if the dielectric is regarded from the point of view of a transmitter of power it will be only reasonable to expect some loss of energy in the transmission, especially as the medium has but little mechanical elasticity. In this connection it is noteworthy that mica and glass condensers have, as a rule, a lower dielectric loss than paper condensers, and these substances have, of course, a much higher coefficient of elasticity than has paper. Further, much higher dielectric losses are shown by condensers impregnated with oil than by those in which paraffin wax is used, this being no doubt due to the fact that the liquid dielectric can move under the influence of stresses set up electrostatically.

I should point out that Mr. Mordey's figure of 13 lbs. per square foot requires revision, inasmuch as the assumed thickness of the dielectric 0·001 in. is too low. The *minimum* with the sample under test is about 0·0016 in., and this reduces the mechanical pressure on the dielectric considerably below the figures quoted.

Dr. Sumpner's remarks concerning the behaviour of condensers of the coated paper type in connection with measuring instruments for "heavy" electrical engineering are of particular interest as breaking comparatively fresh ground, and I am glad to have Dr. Sumpner's testimony to the satisfactory results which he has obtained in his special field from this type of condenser. I quite agree that the Sumpner instruments are more convenient for capacity measurement than the less robust apparatus in use by the National Telephone Company, but both methods have their special advantages.

Mr. Stubbs raises a point which I had not perhaps made sufficiently clear, and I am glad to have this opportunity of elucidating it. In referring to "pinholes" in the foiled paper I had in mind holes existing in the stock prior to its being coated. During the coating process these would become filled with the metallic powder and would consequently cause trouble unless removed by the "breakdown" process. Besides these metal-filled perforations there are, however, numerous other defects or weak places which are literally "broken down" by the electrical pressure. With the old form of condenser breakdowns after manufacture were due in most cases to metallic particles or grit penetrating the dielectric. Furnace ash and abraded metal from machinery were most often the proximate cause.

Respecting the melting-point test, I should explain that the method indicated in Fig. 5 takes only a few minutes—ten at the outside—to carry out, since there is no necessity to proceed beyond the point where the temperature becomes stationary. The method in question

is that adopted by most paraffin refiners; that quoted by Mr. Stubbs, though regularly used in laboratories, was found to take more time and to be less suitable for workshop use. Mr. Mansbridge.

The accuracy of the formula for correcting insulation to standard temperature is being inferentially checked daily, and there seems to be no reason to doubt its accuracy.

Mr. Record's criticism of the name "foiled paper" is justifiable. The name was, however, adopted because it was the recognised trade description of an existing article.

So far as the effective capacity of a condenser with alternating current is concerned, I find that for ordinary frequencies the conductor resistance in the condenser itself has very little effect. Properly made condensers of the coated paper type have been tested at frequencies up to 2,000 periods without revealing any appreciable difference in capacity as between alternating and continuous currents. To produce the best results, however, the manufacturing details referred to in the paper must not be overlooked, particularly with reference to the prevention of creases. Paradoxical as it may seem, it is a fact that rolled condensers of this type can, with reasonable care in manufacture, be made so that even after pressing they contain nothing in the nature of sharp creases.

On the motion of the President a vote of thanks was unanimously passed to Mr. Mansbridge for his valuable paper.

Proceedings of the Four Hundred and Seventy-ninth Ordinary General Meeting of the Institution of Electrical Engineers, held in the rooms of the Royal Society of Arts, John Street, Adelphi, on Thursday evening, May 14, 1908—Mr. W. H. PATCHELL, Member of Council, in the chair.

The minutes of the Ordinary General Meeting held on May 7, 1908, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associated Members to that of Members—

E. McGregor Duncan.

From the class of Associates to that of Associate Members—

Arthur Blok. | Frank Kieffer.

Archibald V. Mason.

From the class of Students to that of Associate Members—

James D. Butcher. | Halsall Owen.
Joseph Meech. | Thomas H. Vitty.

Messrs. S. H. Andrews and W. H. Molesworth were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

William Nisbet Cochrane. | Herbert Alexander Fleet.
Pratt Cordiner. | John Alexander Fraser.
Percy Leonard Davis. | Ernest Henry Rhodes.
Herbert Withers Edwards. | William Vincent Waite.

As Students.

Henry Richmond Climie, B.Sc.	William Thomas Magrath.
Indra Krishna Kaul.	William Pate, B.Sc.

Donations to the *Library* were announced as having been received since the last meeting from Messrs. Charles Bright, E. Guarini, M. Kohl, Longmans Green & Co., the National Physical Laboratory, and W. H. Patchell, to all of whom the thanks of the meeting were unanimously accorded.

The CHAIRMAN: Gentlemen,—The President has asked me to apologise for his absence, as he is representing the Institution elsewhere to-night.

The following paper was then read and discussed :—

SWITCHGEAR CONTROL APPARATUS AND RELAYS FOR ALTERNATING-CURRENT CIRCUITS.

By CHARLES C. GARRARD, Ph.D., Member.

(*Paper received January 28, and read in London on May 14, 1908.*)

1. *Introduction.*—The installation of control relays on high-tension alternating-current circuits has become standard practice, and is likely so to continue. The correct design and lay-out of such relays is of the highest importance. On their proper action a large part of the success of the system depends. Recognising this, it is somewhat remarkable that many systems are in operation to-day designed on wholly erroneous lines. This is due, no doubt, in part, to the fact that the relay control apparatus has not been deemed worthy of great attention in comparison with, say, the performance of the generators and prime movers. Another reason is that of apparent economy. The object of this paper is, first, to deal with a number of such instances which have come under my notice, and secondly, to examine some other systems of control working at present in use or proposed to be put into application.

2. *Polyphase Maximum Time Element Relays.*—A considerable number of such relays have been installed in various supply stations. They consist of a polyphase-wound relay having a single moving element which moves under the action of the currents in two or three of the phases. We will consider such a relay in use on a 3-phase 4-wire circuit, in which case it would have three windings energised by each of the three phases. Let us suppose it to be set to operate after, say, 30 seconds continued overload at 150 per cent. of full load. This means that after 150 per cent. of full load has flowed in *each phase* for 30 seconds the relay operates. It is obvious, of course, that each phase contributes under these conditions one-third of the operating torque in the relay. If T be the operating torque, we may set—

$$T = K\left(\frac{3}{2}c_1 + \frac{3}{2}c_2 + \frac{3}{2}c_3\right),$$

where K is a constant and $c_1 = c_2 = c_3 = c =$ full-load phase current. Suppose now that instead of the overload occurring on each of the three phases simultaneously, it only took place in one phase, as is quite possible on a 4-wire system, due to the breakdown of one phase to earthed neutral. It is clear that in order to operate the relay the overload on the single overloaded phase must be much greater than before.

If the current flowing in the other two phases be the normal full-load current, we get—

$$K(C_1 + c_2 + c_3) = \frac{3}{2} K(c_1 + c_2 + c_3)$$

$$\therefore \quad C_1 = \frac{5c}{2}.$$

This is to say, the current in the single overloaded phase will have to rise to two and a half times the normal full-load current before the relay will operate. Of course, these equations are only illustrative, as the law connecting operating torque and current in a relay is generally more complex than a simple proportion. They, however, illustrate the undoubted fact that with polyphase maximum relays very large and

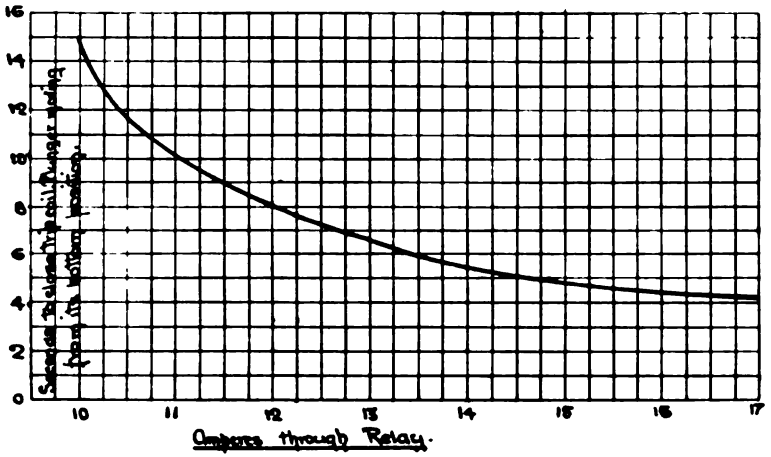


FIG. 1.—Calibration Curve of Solenoid Relay.

dangerous overloads can continue to flow in any one phase without causing the relay to operate and to open the circuit. Polyphase relays should never be used, but always single-phase relays connected entirely separately on two or three of the phases on three or four wire systems respectively.

3. *Polyphase Reverse Relays.*—Exactly the same objection applies to the use of these as to the use of polyphase maximum relays. If, for example, the reverse relay be set for 15 per cent. reversal on any one phase, it is clear that if the reversal occurs on all three phases at once—as, for example, when a bad attempt at synchronising is made—a reversal of 5 per cent. is sufficient to operate the relay, which would be too delicate a setting for the case in question. On the other hand, if a reversal of 15 per cent. in all phases at once is required to operate the relay, a very large reversal in any one phase can take place before the circuit be open-circuited. In fact, under some conditions with a

reversal in one phase only the tendency towards operation in the relay due to this reversal is neutralised by the increased forces in the opposite direction due to the unreversed phases, and the relay quite fails in its action. The only perfect solution is to instal a separate single-phase relay on each phase, either two or three, as the case may be.

4. *Solenoid Relays.*—A considerable number of maximum time-limit relays, operating on the solenoid principle, are in use at the present moment. They consist of a solenoid having a movable iron plunger, which is sucked up when the current in the solenoid exceeds a certain value. The iron plunger is attached to a dashpot or air-bellows which retards the travel of the plunger, the amount of the retardation being

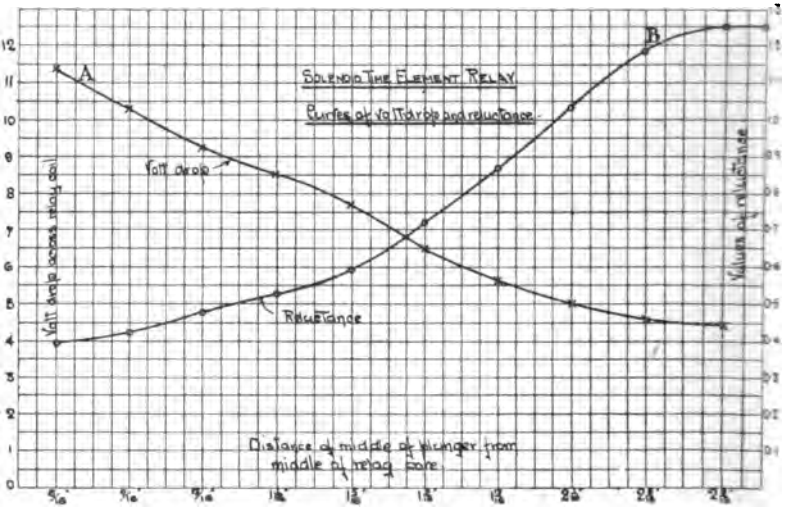


FIG. 2.

varied by means of a small valve which controls the clearance in the dashpot, or the rate at which air can pass in or out of the bellows, etc. Thus the plunger is caused to take a certain time to travel to its top position. When the top position is reached contact is made in the trip-coil circuit and the controlled circuit is opened. A typical relay, made by a well-known firm, operating upon this principle was experimented upon, and its calibration curve is shown in Fig. 1. The coil in this relay consists of about 325 turns of wire. Some measurements made on this instrument are represented in Fig. 2. The current through the coil was maintained constant at 10 amperes, 50 ∿ per second, and whilst the position of the plunger in the solenoid was varied the volt-drop across the terminals of the coil was measured. It will be noted that as the plunger is raised within the solenoid the volt-drop across the same is increased largely, and, of course,

the volt-ampere consumption of the relay goes up. From these measurements and the known ohmic resistance of the coil it is possible to calculate the coefficient of self-induction in henrys L, and from this, and the number of turns S, the magnetic reluctance of the circuit can be calculated from the formula—

$$\text{Reluctance} = \frac{4\pi S^2}{10^9 L}.$$

The variation of the magnetic reluctance of the relay with alteration of the position of the plunger is given in curve B of Fig. 2. As the plunger goes up the magnetic reluctance goes down. Now, with a constant magnetising force in the relay the attractive force on the plunger varies inversely as the square of the reluctance. It follows that if, due to the passage of a certain current through the relay, the plunger is caused to travel upwards, the higher the plunger goes the less the current necessary to keep it in its new position. Thus the current in the controlled circuit can fall again to its normal value, but the plunger will not fall, but remain "floating" for an indefinitely long period near its top position. If, now, the current again increases, the plunger will complete its upward journey, but without any time element whatever, this being due to the fact that the first small movement in a dashpot is unretarded, no matter from what position in its travel the plunger starts.

Experiments made to test this theory confirmed it in every particular. It was found that if the plunger were allowed to travel upwards, due to the passage of an excess current, and the current was reduced to its full-load value before contact had been made in the trip-coil circuit, the plunger did not fall, but remained floating near its top position. The next time the overload came on, the relay closed the trip-coil circuit without any time element whatever. This test is in exact parallel with actual practical conditions. The figures of an actual test are as follows: The relay was adjusted so that contact was made between the trip contacts when 9 amperes (that is, the starting current) flowed through the winding. On reducing the current, however, the plunger did not at once fall. At 7½ amperes the trip circuit was just broken, but not until 5·2 amperes was reached did the plunger fall back to its bottom position. Now, 5·2 amperes in the relay would correspond to about full-load current in the primary circuit. Translated into practical conditions, these results mean as follows: At time of full load a short comes on the system which is intermittent in nature. The current increases sufficiently to pull up the plunger of the solenoid relay, but not for a sufficient time to close the trip contacts. The short goes off, but the full load remains flowing in the circuit. Consequently the plunger does not fall, but remains floating near its top position, and the next time the short comes on the relay operates without any time element whatever, and the whole object of the apparatus is vitiated. These results show pretty conclusively that the dashpot solenoid type

of maximum relay is not to be relied upon for dealing with intermittent overloads or shorts.

5. *Fuse-shunted Trip Coils.*—A method sometimes adopted to impart a time element characteristic to an ordinary circuit breaker is to shunt the trip coil with a fuse (Fig. 3). Normally the secondary current of the current transformer flows through the fuse and not through the trip coil, until the fuse blows and the current is diverted through the coil. The time taken for the fuse to blow gives the time element. It is only possible to use this scheme for alternating currents, as with continuous currents the whole of the current passes through the trip coil, and a sufficient volt-drop to blow the fuse cannot be obtained. The chief advantage of this scheme is cheapness. Its efficiency may be judged from the following considerations. The two essential functions of a time-element device are as follows :—

(1) The time lag should prevent the circuit breaker opening with every momentarily abnormal rush of current.

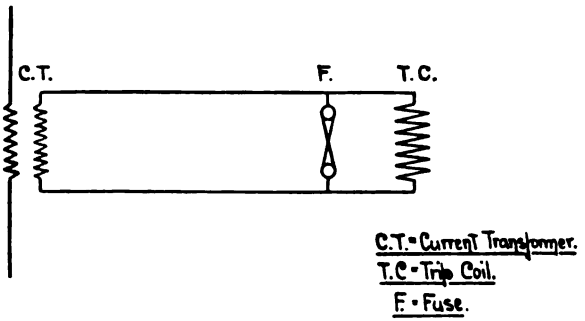


FIG. 3.

(2) A discriminating action should be obtainable—that is, if two time-element circuit breakers are in series, it should be possible to adjust one to open before the other.

The second function is vital in all important circuits. As an example, consider a high-tension feeder going to a sub-station in which motor-generators are working. Maximum time-element circuit breakers would be installed in the generating station on the outgoing feeders, and also in the sub-station between the busbars and the motors. In the event of a dangerous overload on a machine, it is necessary that its circuit breaker should operate before that installed on the feeder at the generating station. If this happens the faulty machine is cut out satisfactorily and a disturbance of the supply does not result. The point to be ascertained is how far this discriminating action can be attained. The following experiments were made to elucidate this :—

The trip coil used was a standard 10-ampere one, having a volt-drop of 2·8 volts at 50 ∿, the plunger being set so that it was pulled

up with 10 amperes through the coil. In order to approximate to working conditions, the current through the coil and fuse in parallel was kept constant at 8 amperes and then suddenly increased by definite amounts, and the time noted which elapsed before the trip coil operated. Curves (Fig. 4) give the results obtained by varying the thickness of the copper fuse wire. It will be seen that altering the thickness of the wire not only alters the current at which the combination works, but also affects the time element enormously. Thus independent adjustments of the time and the current calibrations are not feasible—at least, if fuse wires of constant length and of the same material are used.

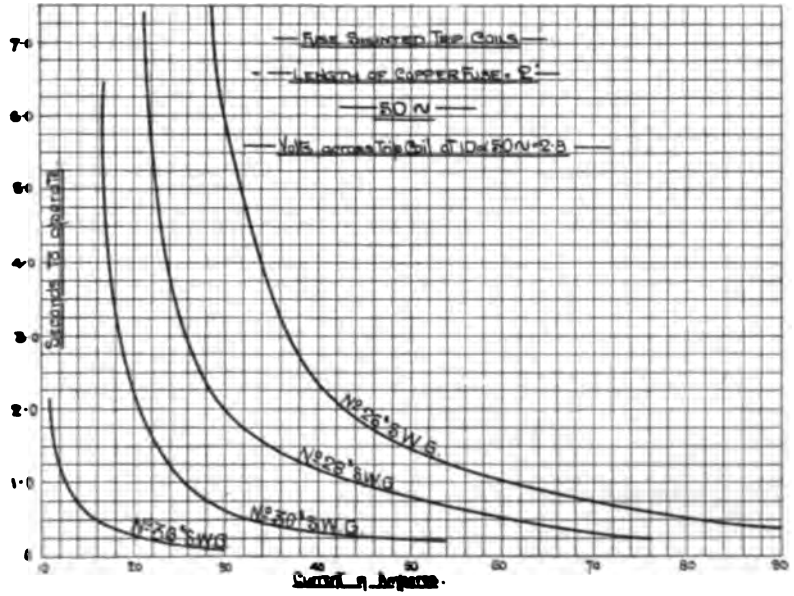


FIG. 4.

The resistance of 2 in. of No. 30 S.W.G. copper wire is 0·011 ohms at 60° Fahr.

As the impedance of the trip coil is 0·28 ohms, it will be seen that practically all the current flows through the fuse. It follows that regulation of the current at which the arrangement works can only be effected by altering the fuse wire, and simply raising or lowering the plunger in the solenoid will have no effect.

A characteristic of all the curves of Fig. 4 is that on large overloads the times taken all become practically zero. That is to say, on heavy overloads any time discrimination disappears altogether.

It might be urged that as putting in a thicker wire both increases the time element and also the current at which the combination

works a solution of the problem may be obtained. It must be remembered, however, that the current through the fuse is the *secondary* current of a current transformer, and, although the primary current in the generating station may be larger than the primary current in the sub-station, yet, the secondary currents are generally equal, the ratios of the current transformers being varied according to the values of the primary current. For important distributions, therefore, the fuse-shunted trip coil is not suitable. It may, however, find useful application on motor-control panels where ordinary fuses are not desired, and where a discriminating action apart from the prevention of the machine being cut off due to every temporary overload is not wanted.

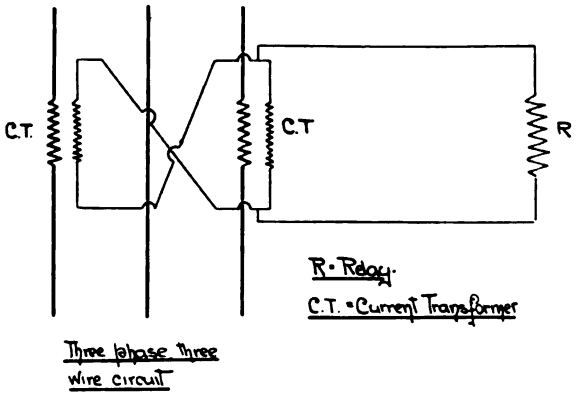


FIG. 5.—Faulty Relay Connections on 3-Phase 3-Wire Circuit.

6. *Maximum Relays connected on the "Resultant Principle."*—

(*a*) 3-PHASE 3-WIRE SYSTEMS.

For 3-phase 3-wire systems two separate single-pole relays are theoretically necessary to afford complete protection. When what may be designated the "resultant" scheme of connections has been used a single 1-phase relay only has been installed, but in conjunction with two current transformers, so connected that the current in the relay is the vectorial resultant of the current in each of the phases in which the current transformers are situated (Fig. 5). A superficial examination would lead one to think that as the relay current is the resultant of the currents in the two phases, an overload in either will cause the relay to operate and thus afford complete protection. A number of supply stations in this country have protective apparatus installed in this manner. On working out the currents in the relay vectorially, however, it will be found that the protection afforded by this method is doubtful. We will assume the normal full-load secondary current of the transformers to

be 10 amperes, and that the relay is set to operate at 200 per cent. of full-load current; that is, it will operate when 34·6 amperes flow through it. If now the overload occur on both the phases connected to the relay, and the phase displacement in each phase is the same, then the circuit is opened when 20 amperes secondary current flows in each phase. It is quite likely, however, that the overload will only occur in one of the phases, and in this case the phase displacement will most probably not be the same in each phase. If the angle of lag in each phase is equal, and only one of them is overloaded, it will require 282 per cent. full-load current in the single overloaded phase to cause operation. Should, however, the current in the overloaded phase lag 60° more than the other phase, which is quite possible, then the current in the overloaded phase would have to increase to 386 per cent. of full-load current before the circuit is broken. That is to say, with this scheme of connections and the circuit breaker set so

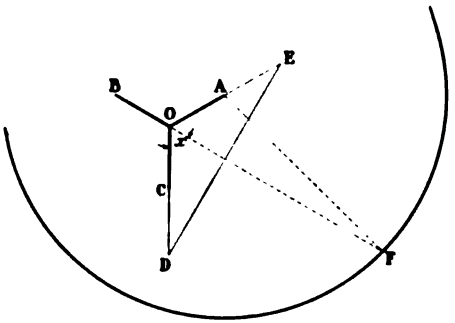


FIG. 6.

that it comes out with the ordinary test at 100 per cent. overload, one of the phases, and of course the unprotected phase, could be overloaded to the extent of 200 per cent. or 300 per cent. overload without the circuit being opened. It will be agreed that such a scheme of protection is somewhat illusory.

The figures given above can be obtained from a simple clock diagram (Fig. 6). The three full-load normal currents are O A, O B, and O C. If O E = 2 O A, then E D = the current through the relay which causes it to operate. If a circle with radius = D E be struck from A as centre, then the current flowing in the phase O C for any particular angle of lag x is O F, it being supposed that the current O A remains constant. The two current transformers are, of course, in phases O A and O C.

(*b*) 3-PHASE 4-WIRE SYSTEMS.

The 3-phase 4-wire system is shown in Fig. 7. It will be seen that three current transformers are necessary, but only two relays

are used, the idea being to save the cost of the third relay. At first sight it would seem that, as—

$$\text{Current in } R_1 = \text{current in } c + \text{current in } a,$$
$$\text{and Current in } R_2 = \text{current in } b + \text{current in } a,$$

there could not be an abnormal current in any one of the three

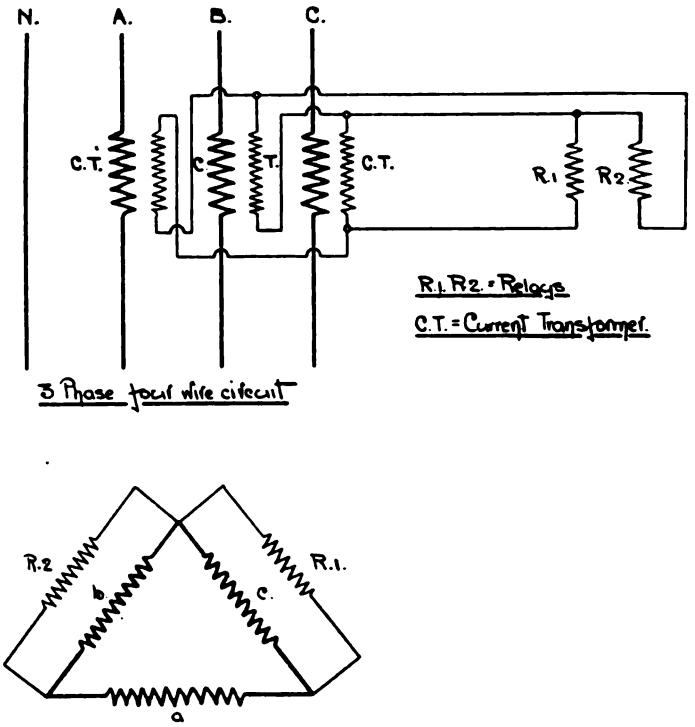


FIG. 7.—Faulty Relay Connections on 3-Phase 4-Wire Circuit.

current transformers without there being a corresponding current in R_1 or R_2.

Exactly the same consideration, however, can be applied to this case as in section (*a*), as it is quite possible for one phase to be overloaded since it has a return path through the fourth wire. If this overload has a large phase displacement relative to the currents in the other phases, then the condition may arise of very big overloads in the one phase and the circuit breaker not operating.

The only safe arrangement is to have the same number of relays as current transformers. If the circuit be a 4-wire one, then three relays are necessary; if 3-wire, then only two relays are essential.

7. *Alternating-current Reverse Power Relays.*—Such relays are installed between busbars and sources of electrical energy; thus they are used for controlling generator switches and the switches at the far ends of feeders. In such positions complete protection is afforded by the reverse relay, and the installation, in addition, of maximum current circuit-breaking apparatus at the same places must be regarded as bad practice. The requirements to be met on generator circuits and on the ends of feeders are, however, different, and also vary with the type of prime mover.

8. *Reverse Relays on Generators.*—These should only come into operation when a serious fault has developed on the generator or prime mover of the nature of an insulation breakdown in the winding, or a total failure of steam power. A short consideration will show several cases of accident to the prime mover, in which an automatic disconnection from the busbars would only be an aggravation of the trouble. For example, consider two or three large compound Corliss engines, with 3-phase generators running in parallel. A not uncommon fault is the failure of one of the admission valves to open, with the result that steam is admitted to only one side of the piston. Under these circumstances a large surging current passes backwards and forwards from the faulty to the good machines. This is due to the very uneven turning moment in the engine caused by the unequal distribution of steam in the cylinders. The wattmeter and ammeter needles are set into a violent state of oscillation, but the generator remains in step. The fault with the valve is but a small matter, and is noticed at once by the driver, who attends to it immediately, the surging current ceases, and everything goes on as before. If, however, this set had been cut off the busbars, the other generators would have become seriously overloaded, with probable variation in volts, and all the trouble of synchronising would have had to be gone through. A satisfactory generator reverse relay should withstand therefore, without operating, such a surging of power from one machine to the other, provided the two remain in synchronism. These surges into the faulty set are, of course, reversals, and, moreover, of considerable magnitude.

From this instance it follows clearly that a generator relay which operates instantaneously on a reversal is not desirable. In fact, it cannot, under the above set forth circumstances, be used at all.

9. *Failure of Field Current of Generator.*—With the diminution or total failure of the field current of a generator, the current in the windings increases greatly and leads considerably on the machine volts. Provided the set remains in synchronism, and the steam supply is in order, the alternator continues to supply energy to the system, and there is no reason why it should be disconnected from the busbars. The large increase of current is noticed by the switchman, who immediately seeks for and remedies the fault without any serious disturbance of the supply. If when the field circuit fails the set drops out of step, then it should rightly be disconnected, but this would

generally follow, as, with the set out of step, a large flow of power into the machine from the busbars would most probably take place.

10. *Effect of Reduction of Busbar Voltage on Generator Reverse Relays.*—It will be understood that any form of relay, one of whose constituent parts is a shunt coil, will be affected by variation in the voltage applied to the same. The shunt coil of the generator reverse relay is excited (through the intermediary of potential transformers) directly from the busbars. On the occasion of an accident to one of the generators the busbar volts will tend to go down. The trouble is intensified by the fact that, as has been shown, an instantaneous relay cannot be used, therefore there is more time for the voltage to fall. It must be remembered, however, that a failing generator in parallel with one or more good ones is not likely to pull the volts down to any very

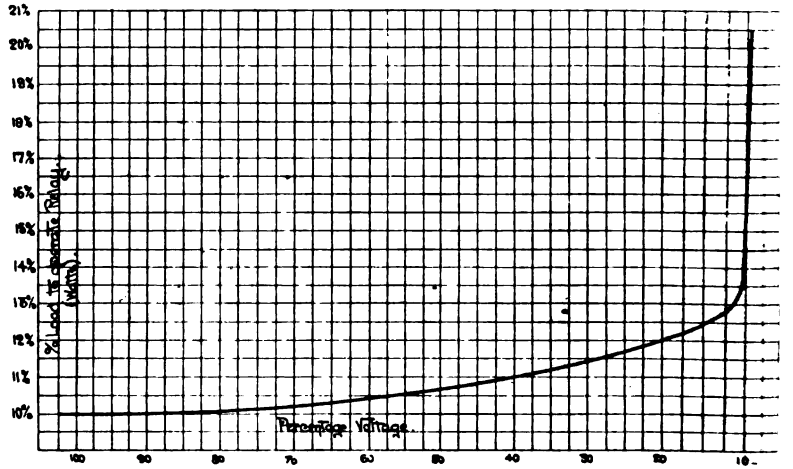


FIG. 8.—A.C. Reverse Relay—Variation of Calibration with Voltage.

alarming extent. Probably a 50 per cent. reduction is the maximum to be expected. It is clear, however, that the calibration of the relay should be as little affected by variation in the busbar voltage as possible. Curve Fig. 8 shows the effect of reduction of the shunt voltage on the calibration of a reverse-power relay, consisting of a specially designed wattmeter movement. It will be seen that the calibration is practically unaffected down to 10 per cent. of the normal voltage. The limit down to which it works is 7 or 8 per cent., below that it becomes inoperative. The relay is also absolutely inoperative on forward power under all conditions. Tests made up to ten times full-load power in the forward direction proved this.

11. *Setting of Reverse Relay on Generators.*—The most suitable value to which a generator reverse relay should be set is such that it will operate, after the requisite time element, with an energy reversal of

10 per cent. of the full rating of the machine. With this setting the current which can flow in the generator windings is never very excessive. It has been suggested that 10 per cent. is too fine. A case which came under my notice was that of some triple-expansion three-crank engines, driving 6,600-volt 3-phase generators. These engines were fitted with emergency stop valves. Owing to the method adopted for operating these valves, they would occasionally close accidentally and shut off the steam. Under these conditions the energy reversal would exceed 10 per cent., and therefore a 25 per cent. setting was asked for, so that the machine should not be cut out of circuit, but remain in step, allowing the driver time to open the valve again. The proper cure for the trouble would be, however, to arrange the emergency valve so that it did not operate in this accidental manner.

12. *Reverse Relays at the Ends of Feeders.*—The function of such relays is to prevent a fault on the feeder being fed back from the sub-station or distribution network. The currents which flow into such a fault will have passed through long lengths of feeder, the C R and inductive drop in which will cause the voltage applied to the shunt of the relay to fall. Thus reverse relays, situated at the ends of feeders, are far more likely to be affected by drop in volts than are those on generators. For this reason it is desirable for the relay to operate as quickly as possible after the occurrence of the reversal. The objection to instantaneous reverse relays on generators does not apply here, as a similar action to the slow surging of current, or cross-current, from one generator to another cannot take place. Temporary reversals of energy in a feeder may happen, however, due to hunting of the sub-station machinery. The hunting may be set up by a temporary disturbance in the system, such as a short circuit with consequent lowering of voltage. With an instantaneously operating relay the first reversal, providing it be of sufficient amplitude, will cause the relay to operate, and thus the circuit may be opened when there is not any need for it. As the time-limit relay is inadmissible, this action must be obviated by other means. The determining factor is obviously, to what degree may hunting occur in the sub-station machinery without the same falling out of step? Naturally if it be going to fall out of step the opening of the circuit is an advantage. On the other hand, a moderate temporary swing might be set up between the sub-station and the generating station, which will be damped out immediately and not do any harm. The instantaneous reverse relay at the far end of the feeder should be set, therefore, so that the minimum power required to operate it should be above that likely to flow back, owing to such a harmless hunting of the sub-station machinery. It follows that the feeder-end relay should be set proportionately higher than the reverse relay on the generator; probably if it were set to operate at 25 per cent. of the normal full-load capacity of the feeder it would form the most suitable arrangement. Other considerations also indicate that a higher power setting of the feeder-end relay than the generator relay is admissible. With the latter the

motoring current may be of very low power factor, and in order to keep the current within moderate limits the power setting of the relay must be kept relatively low. The feeder-end reverse relay is intended, however, to prevent a feeding back into an earth or short circuit. Such current would be of high power factor, and, if not interrupted, of considerable magnitude. Thus the high watt setting of the relay is justified.

13. *Protection of Interconnector Cables.*—Interconnector alternating-current cables are used generally to connect up one sub-station with another. The ordinary system of generating station and sub-stations without interconnectors is shown in Fig. 9A. To guard against stoppage of supply it is necessary to have at least one spare cable to each sub-station. With an interconnector cable between S_1 and S_2 (Fig. 9B), however, the necessity of these two spares is done away with. Also in many cases the distance S_1 S_2 is shorter than the distance from either sub-station to the generating station, so that the interconnector results in a saving in capital expenditure. The standard method of protection

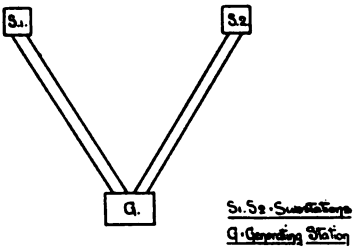


FIG. 9A.

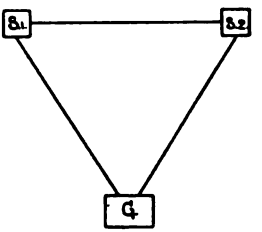


FIG. 9B.

for ordinary feeders is by means of an inverse time-limit maximum circuit breaker at the generating station end and a reverse circuit breaker at the sub-station end. It is obvious that this system is not applicable to the interconnector, as power may flow either from S_1 to S_2, or from S_2 to S_1. In fact, if S_1 and S_2 are running in parallel the direction of flow in the interconnector will alter according to the relative loading of the sub-stations.

14. *Conditions under which the Interconnector should be Automatically Disconnected.*—A diagrammatic representation of a generating station feeding two sub-stations connected together by an interconnector is given in Fig. 10. It is obvious that the interconnector should be protected against excessive loads going through it of such a magnitude that the cable itself is likely to be damaged. It is conceivable that owing to faulty superintendence the current in the interconnector may mount up to such an extent that damage to it may result. Some kind of a maximum circuit-breaking device is desirable therefore, and as the only object of this is to prevent thermal damage, the time element should be very long—longer than any of the other maximum circuit breakers on the system, whose function it is to deal with shorts and

accidental temporary overloads. For shorts and overloads on the system, other than those caused by the failure of the interconnector itself, the circuit breakers on the feeders, motors, and generators must be relied upon. The interconnector, from the point of view of control, virtually makes two sub-stations into one—that is, it is a prolongation of

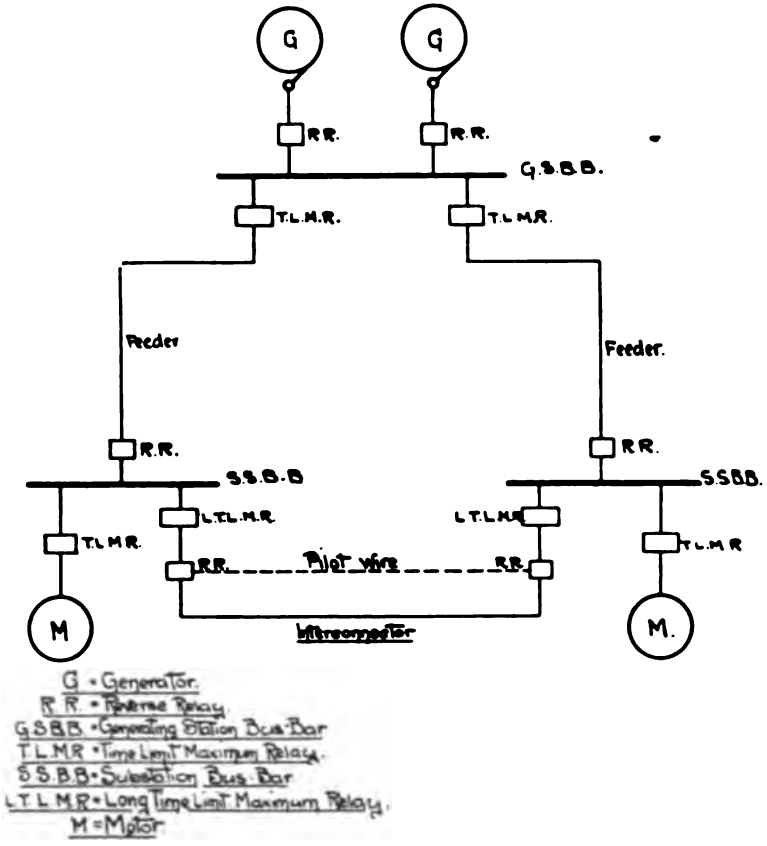


FIG. 10.

the sub-station busbars. So long, therefore, as the interconnector is in good condition, and not permanently overloaded sufficiently to be burned, overloads and shorts on the system should never cut it out of circuit. The occasion when it should be cut off is when it goes wrong itself either by grounding or shorting. It is obvious that to attain this end something more is needed than simply maximum or reverse relays at either end of the interconnector, as these cannot discriminate between shorts or grounds in the interconnector, or in other parts

of the system. To solve the problem it is only necessary to consider that the function of the interconnector is to pass energy from one sub-station to the other in either direction. So long as it is doing this it may be said to be performing its function. It is, however, not doing so when it takes energy from one sub-station and does not deliver it to the other—that is, when energy flows into the cable at both ends at the same time. It follows that a circuit-breaking apparatus must be installed at either end, and that these must be interconnected together. This is done generally by means of one or more pilot wires.

15. *Merz and Price's System.*—The principle on which this method depends is illustrated in Fig. 11. A current transformer (C.T.) is included in the interconnector at either end, the secondaries of which are connected together through the trip coils (T.C.) and the pilot, the return circuit being *viâ* earth. So long as the current flows through both current transformers in the same direction, it is immaterial in which direction, the E.M.F.'s induced in the secondaries of the C.T.'s balance, and current does not flow through the pilot and trip coils. So soon, however, as the currents at either end become unequal, or a reversal at the one end relatively to the other takes place, current begins to

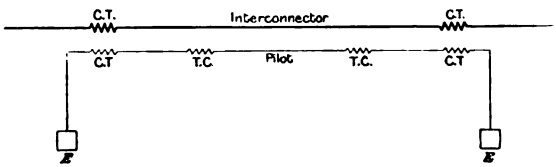


FIG. 11.—Merz and Price's System of Protection of Interconnections.

flow in the trip coils, and when this has reached sufficient value the switches are opened. It may be mentioned that differential relays are used usually, in addition, for operating the tripping mechanism of the switches as the arrangement of Fig. 11, although quite right theoretically, cannot be applied practically in the simple form shown.

The advantage of Merz and Price's arrangement is that potential transformers are done away with altogether. In order to secure full protection, however, more than one pilot wire has to be run for each 3-phase interconnector.

16. *Protection of Interconnector Cables by means of Electrically Interlocked Reverse Relays.*—As the criterion of failure of an interconnector is the simultaneous flow of power into it at either end, such a circuit can be protected by the installation of reverse power relays at both ends, both relays being connected in a common tripping circuit arranged so that only when energy is flowing into the cable at both ends is the trip-coil circuit closed at both relays, and the main switches caused to open circuit (see Fig. 12.) Normally the trip circuit is broken at one relay and made at the other, or *vice versâ*, according to the direction of flow

of power in the circuit. The relays close circuit with a slight time element so that, on the flow of current reversing, one of the contacts is opened at the one relay before the other one is closed. On reference to Fig. 12 it will be seen that only when power is flowing into the

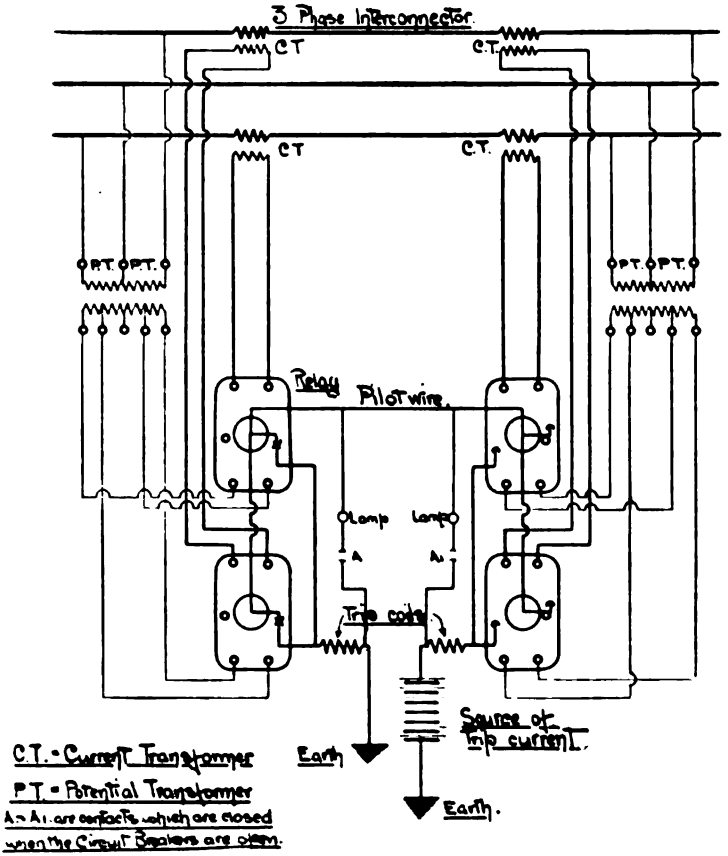


FIG. 12.—Protection of 3-Phase Interconnector by means of Electrically Interlocked Reverse Relays.

cable at both ends at the same time is the trip-coil circuit complete through each trip coil and the circuit ruptured at both ends.

A and A_1 are each a pair of contacts which are closed automatically when the main circuit breaker at the corresponding end opens. Thus, if the switch at the left end of the interconnector opened slightly before the one at the right-hand end, the trip-coil circuit would be closed at A and by the relay at the right-hand end. Thus the circuit breaker at the

right-hand end would also operate. The object of this arrangement is to ensure that both ends of the interconnector will be disconnected even if the two switches do not act quite as quickly as each other. Each trip coil is also arranged so that it is cut out of circuit when its main switch has opened circuit, after, however, A (respectively A_1) has been closed. The trip coils, therefore, experience no danger of burning out. The state of affairs might, however, arise that the left-hand switch was open and the right-hand switch was closed, there being a short or earth on the interconnector. By the act of closing the right-hand switch the trip coil of this switch will be put into circuit ready for operation, and the circuit through the same will be complete through the right-hand relay, which operates due to the flow of current into the fault, and through A. Thus the right-hand circuit breaker will be opened, while at the same time cutting out its own trip coil. Thus it is impossible to connect up the interconnector at either end while there is a fault on the same.

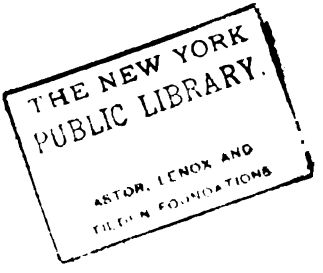
The arrangement as set forth above of course necessitates that there should be some voltage in order to operate the relays. If the voltage absolutely disappears, the reverse relay will not work, and it may be thought that in the case of a very bad short circuit this will happen. Considerable experience has shown, however, that even under the worst conditions the voltage does not entirely disappear, and that if the calibration of the apparatus is unaffected by fall of potential down to 10 per cent. of the normal working voltage all working conditions will be met (compare Fig. 8).

As the pilot wire only carries the tripping current it will be seen that only one pilot is necessary whether the relays are single, 2-, or 3-pole. On a 3-phase system the relays will be 2- or 3-pole according as to whether the system be 3-wire or 4-wire. Messrs. Merz & Price suggest that the pilot wire, or wires, can be made up in the same multicore cable as the main conductors, there being generally sufficient space for this in the filling, which is used to make up the cable to a cylindrical cross-section. This, however, is open to the serious objection that if a serious fault or burn-out occurs the pilot wire will be broken most probably. It would be much better to keep the pilot wire quite distinct from the main cable, preferably laying it in a different duct. A system, therefore, which under all conditions only requires one pilot wire is of advantage in this direction.

17. *Time-limit Maximum Circuit Breakers.*—At the present time it is general practice to instal time-element maximum circuit-breaking devices, in various positions, on all large systems. There have been a variety of forms used. Some have had a constant time element independent of the degree of the overload. These are but rarely required, and we will only consider inverse time-element circuit breakers. In reading descriptions of the various plants in different parts of the world, it is very difficult to arrive at any conclusion as to the actual time element employed. It is very common, for example, to read that the time element in such and such a switch was 2 seconds. This does not convey any clear meaning. In order fully to understand the



FIG. 13.


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TILDEN FOUNDATIONS

arrangement it would be necessary not only to know at what current the switch just opens and in what time, but also the time taken on a dead short circuit which, of course, is very different. It is this latter time which fixes the order of succession in which inverse time-element circuit breakers, which are in series one with another, operate on heavy short circuits. Hitherto it has been considered generally that fuses possess an inverse time-element action. It must not be assumed that this is always the case. R. P. Jackson * gives oscillograms of 38,000-volt (phase to earth) expulsion fuses, which show that these operated

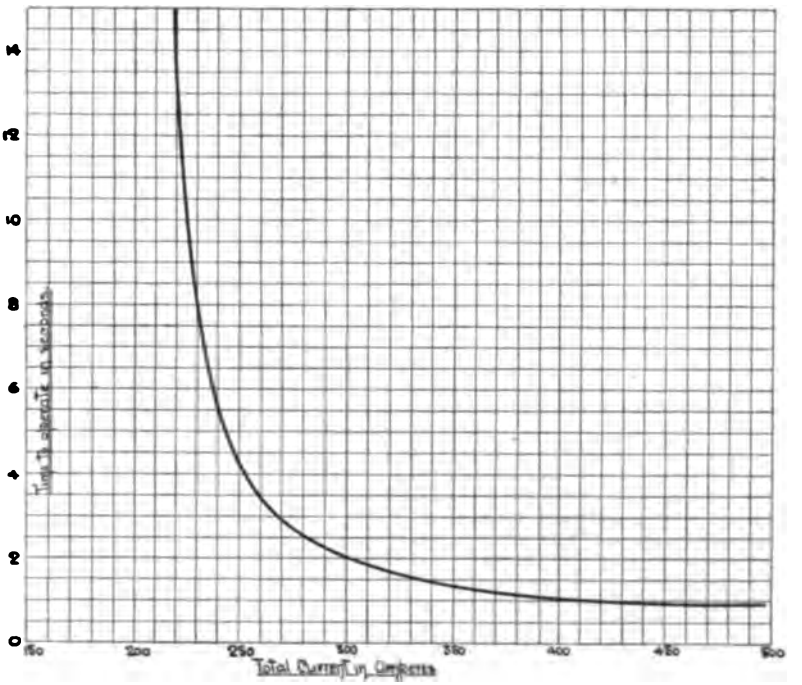


FIG. 14.—Time Element of High Tension Fuse.

in one or two cycles. It is, however, often true. The photograph in Fig. 13 illustrates a 105-ampere high-tension fuse which has been used on the outgoing feeders in the 50-~ generating station referred to later. These consist of seven strands of No. 24 S.W.G. silver wire, each strand being enclosed in a small glass tube, for a short distance in the middle, the whole being surrounded by an outer glass tube. The wires are spaced out by asbestos washers, and the outer tube is filled with French chalk, except for the small space in the middle where the wires are enclosed in the small glass tubes. The engineer has kindly informed

* *Transactions of the American Institute of Electrical Engineers*, vol. 25, p. 896, 1906.

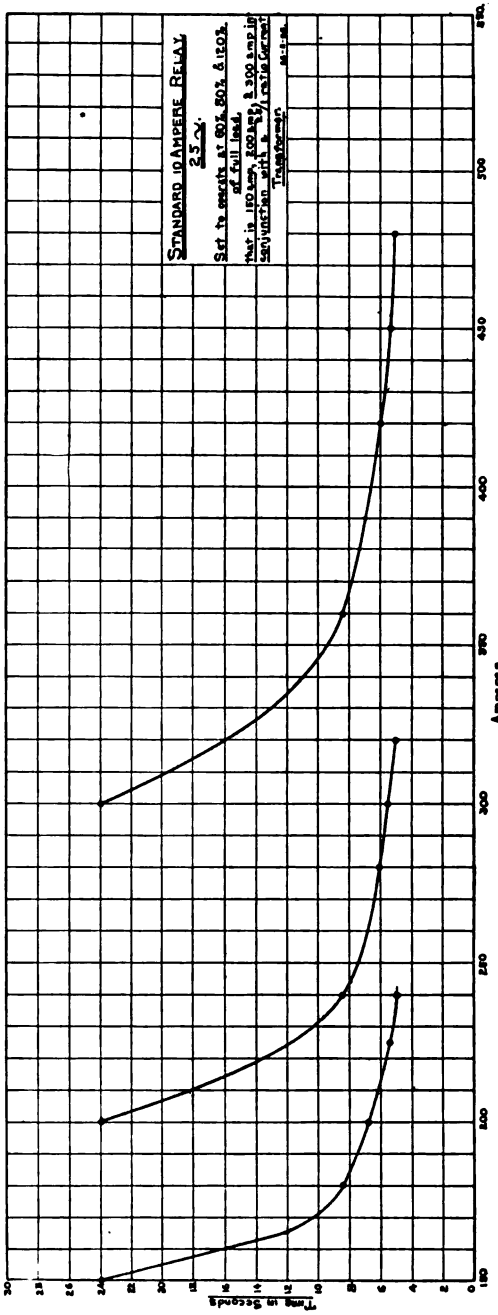


FIG. 15.

me that these fuses have never blown due to shorts on the low-tension network. Whenever they have blown it has been due to a failure in the feeder, in that part of it between the generating station and the first sub-station. The time element of this fuse is given in the curve in Fig. 14. This curve was taken by keeping 80 amperes flowing through the fuse till normal temperature was reached, then suddenly increasing the current to the value given in the curve, and noting the time taken to blow.

Of course, apart altogether from the difficulty of arranging two fuses in series with the certainty of one operating before the other, high-

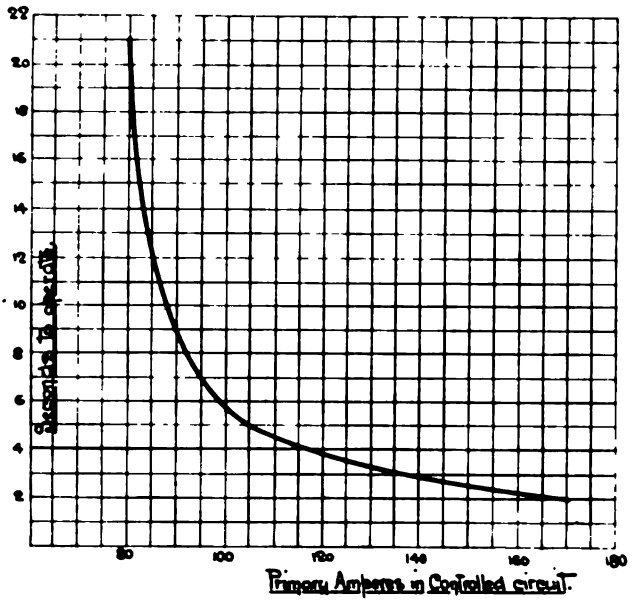


FIG. 16.—25-~6,600-Volt Sub-station Maximum Time Limit Relay with Induction Motor Generators in Sub-stations.

tension fuses cannot now compete with automatic circuit breakers either in cost or efficiency.

18. *Inverse Time-limit Circuit Breakers on Feeders.*—If it has been decided that a time-element circuit breaker is necessary on the outgoing feeder the next point to determine is what this time element should be. If it were only a question of arranging the various switches so that they opened in a predetermined order the feeder time lag would be made as long as possible, as, naturally, the longer it is the more chance have the distant circuit breakers of operating before the feeder. Fig. 15 shows the calibration of outgoing feeder relays installed on the 6,600-volt 25-~ 3-phase feeders in a large generating station in Scotland. I am indebted to the chief engineer for the curve in Fig. 16, which

shows the curve of the switches which are installed on the machines in the sub-stations. The curves of Fig. 15 were arranged so that, under all conditions, the machine breaker should operate before the feeder breaker had time to do so. These settings have proved to be satisfactory on the system in question. The sub-station machinery in this case consisted almost exclusively of induction motor-generators.

Relays having time elements, as in Fig. 15, were subsequently installed on the outgoing feeders in a similar English 6,600-volt system, except that in this case the sub-station machinery consisted almost exclusively of 50-~ synchronous motor-generators. The difficulty was at once experienced that with the comparatively long time elements whenever a severe high tension short came on the system, the shock

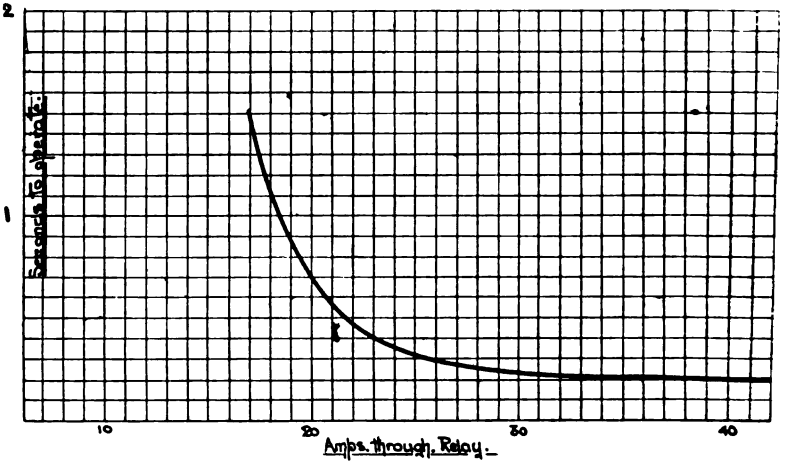


FIG. 17.—Calibration Curve of Outgoing Feeder Relays feeding Sub-stations containing 50-~ Synchronous Machinery.

was so great that a great deal of the synchronous sub-station machinery fell out of step. Generally a swinging of the current to and from the sub-stations was set up which increased until the motors fell out of step. To get over this the time elements were shortened several times until the calibration curve as given in Fig. 17 was obtained on the outgoing feeders. It is considered that with such settings the system will be able to clear itself of high-tension short circuits without any danger of affecting the synchronous machinery other than that fed by the faulty feeder.

It will be seen that in order to prevent the falling out of step of the synchronous machines the advantage of the long time-element circuit breakers has (in this case) to be dispensed with. On examining Fig. 17 the thought arises, Is this very short time element worth keeping? Would it not be just as good to go the "whole hog" and abolish the time lag altogether?

This may seem a plausible thing to do, as it might be considered that the difference between Fig. 17 and an instantaneous action is inappreciable. Really, however, this is not so, and there is more difference between curve No. 17 and an instantaneous action than there is between curves Nos. 15 and 17. In order to get an idea as to what time a so-called instantaneous release mechanism took to work, an ordinary alternate-current trip coil was investigated. An examination showed that the time taken for the plunger to rise from the bottom to the top position did not exceed $\frac{1}{10}$th of a second. It follows that the time element of an instantaneous release is less than $\frac{1}{15}$th of the time element shown in the curve No. 17, and to go from this curve to the instantaneous release is a larger step than the sum total of the previous steps taken in arriving at curve No. 17. There is no doubt that instantaneous releases have been tried and found unsatisfactory by reason of too often and unnecessary operation. If now it should be found that the transitory currents that have given trouble with the instantaneous release are of shorter durations than the times of the curve in Fig. 17, then the retention of the time element, even if shortened to the extent of Fig. 17, is desirable. The general conclusion to be drawn from these notes is that the necessary and desirable time elements of the circuit breakers on each system must be determined experimentally. When installing maximum relays, therefore, they should be such that their time elements may be varied within wide limits independently of the currents at which they operate. It is not desirable to have the time element too easily adjustable by means of a screw or some such arrangement outside the relay, as this provides grave danger of the time settings being altered by unauthorised persons. The time elements of all the circuit breakers on the system must be considered as a whole, and after the correct values have been found the settings need never be altered. The curve in Fig. 14 gives a time element which need not be exceeded on the outgoing feeders on the 50-$\sim$ synchronous sub-station system considered. Relays set with longer times than this resulted in the synchronous motors falling out of step when a high-tension short came on the system, and to get over this difficulty very short time settings had to be resorted to. This entailed a sacrifice of a great deal of the possibility of arranging a selective action of the circuit breakers in series one with another. It would, however, be inadvisable to resort to absolutely instantaneous-action circuit breakers on this system. Much longer time elements can be used on a system consisting of induction motor-generator sub-stations, and therefore a better grading of the circuit breakers can be obtained.

Referring to the question of the protection of interconnector cables (paragraphs 13, 14, 15, and 16), it often happens that continuous current is not available in the sub-station. Fig. 12 shows the system with direct-current tripping coils, and Fig. 18 shows the system for the protection of interconnectors by means of electrically interlocked reverse relays, using alternating-current tripping coils.

Referring to Fig. 18, it will be noticed that when power is flowing into the 3-phase interconnector at both ends at the same time, the

reverse relays R.R. operate and close the circuit through an auxiliary relay A.R. This auxiliary relay A.R. can be energised from a few primary or secondary cells. If the pilot wire consist of $\frac{7}{14}$ cable, this only has a resistance of about $9\frac{1}{2}$ ohms a mile, so that it will be seen

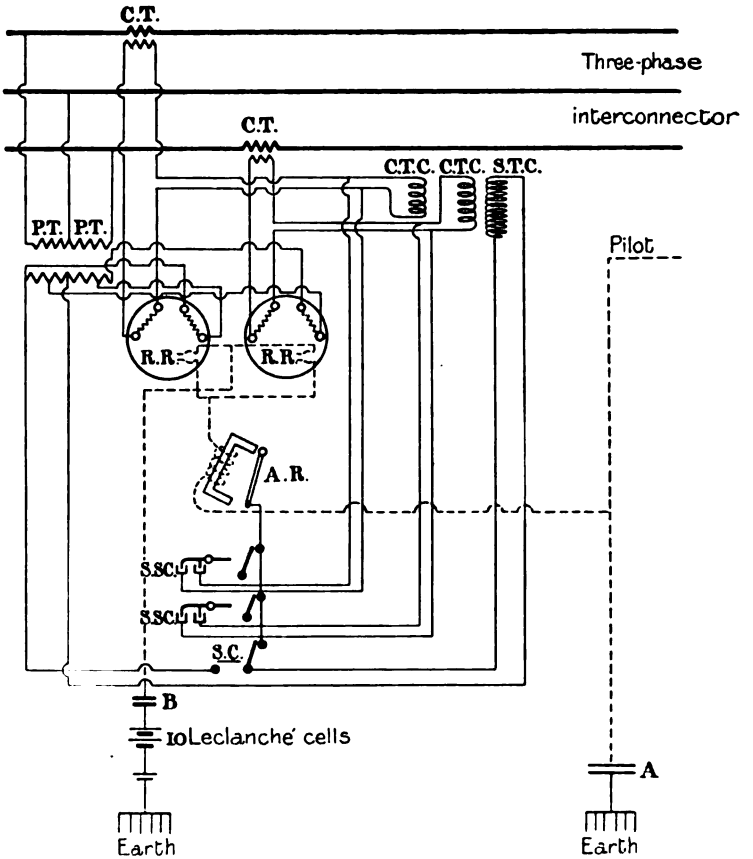


FIG. 18.—Protection of Interconnectors with A.C. Tripping (Series and Shunt).

A and B are contacts on the main switch. A is closed when the switch is open, B is opened when the switch is opened. They consist of simple metal tongues on the mechanism of the switch. The other end of the interconnector is fitted up in exactly the same manner. Both A and B may be shunted by press-button key for testing purposes if desired. The two batteries are connected up so that they are in series.

that quite a small voltage given, say, by some Leclanché cells, is quite powerful enough to operate the auxiliary relay.

Fig. 18 shows both series and shunt tripping. The series and shunt tripping is resorted to so that the interconnector shall be disconnected no matter what the voltage or the current may be which may be avail-

able to operate the trip coils. Thus, if the voltage drops, this will be due to a large current passing, and the series trip coils will be effective. If, on the other hand, but little current passes, the voltage will keep up and the shunt trip coil will be the one that operates. It will be noticed that under normal conditions the current trip coils C.T.C. are shorted by means of the contacts S.S.C. Only when the auxiliary relay A.R. operates is this short circuit removed and the current from the current transformers diverted through the trip coils.

Another point I would now like to mention is in connection with paragraph 18 and the time taken by an instantaneously acting trip coil to operate. Professor B. Hopkinson* carried out experiments on magnetic blow-out and carbon break-circuit breakers on continuous current, and found that they opened the circuit in time periods of the order of one-twentieth of a second. It is probable that an oil break-circuit breaker with solenoid release opens the circuit quicker than this. It will be noticed that my own deduction was less than one-tenth of a second.

Discussion.

Mr. H. W. Clothier: With regard to the introductory paragraph, there has been a good deal of misunderstanding on the subject of relays. When a bad fault has occurred on a system it has generally been the practice to look around and see which parts of the system have been needlessly isolated. It has become, as it were, a second nature with our engineers to expect these discrepancies in the operation of their gear. One of the worst offenders in this respect has been the reverse-current relay. Although I have discussed the subject of protective gear with many engineers I have very seldom found one who is in thorough sympathy with the use of reverse-current relays or reverse-power relays as Dr. Garrard calls them. Mr. Andrews has from the earliest stages been the chief instigator of them, and the work he has done on them has been very great, but notwithstanding, we still have to face the danger of reverse-current relays tripping when they should not trip, particularly when there are disturbances affecting the voltage. I may state as an interesting fact that on the supply systems in Northumberland and Durham when they had reverse-power relays installed they found so much trouble with them tripping at the wrong time that they have now been removed from the generator and feeder circuits. With regard to time-element relays, I think these are almost as undesirable because they allow the excess current occasioned by a fault to be maintained on the system, with the result that the synchronous machines are thrown out of step and the whole system disorganised. I see that the author rather advocates a time-limit attachment to his reverse-power relays. This, I admit, may avoid a good deal of trouble due to the relays tripping out on momentary surges. But at the same time by putting a time element on the Mr. Clothier.

* *Minutes of Proceedings of the Institution of Civil Engineers*, vol. 151, p. 3, 1902.

Mr. Clothier.

reverse-current relay the same objection as stated against the use of time-limit overloads is introduced. The successful features of a feeder protection system on any large high-tension network are these :—

The gear must operate instantaneously; it must cut out the fault before the current has risen to dangerous dimensions and obviate the chance of serious surging.
The gear must be as simple as it can be made.
It must be applicable to all systems of network.
It must not cut out a healthy section for a fault developed on another section.

The Merz-Price system explained in the paper—there are one or two details which are not quite correct, but the main principle is described aright—is the only system I know of that complies with the foregoing conditions.

Dr. Garrard's proposal of interlocked reverse-current relays is certainly ingenious, but it does not cover all the requirements. There are, I think, some serious objections, thus :—

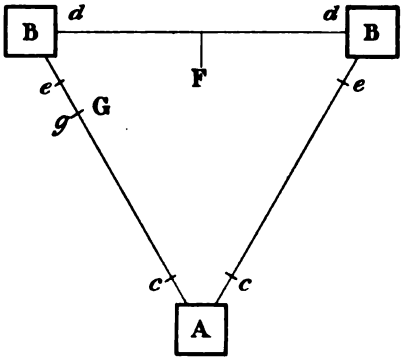


FIG A.

In the sketch (Fig. A) A is the power station. B B are the sub-stations oined to form a ring main having time-limit overload relays at C and reverse-current relays at *e*, and interlocked reverse relays at *d* according to the paper. With all switches closed and subject to the reverse relays not failing a fault at F may be cleared all right. But suppose a switch is open at G and a fault now develops on the interconnector at F, there is no current fed through from the left to oppose the current from the right, and therefore the protective gear becomes inoperative and the fault is not cleared by the relay *d*.

Secondly, it has the objection inherent to the use of time limit, in not cutting out the fault instantly.

Thirdly, it is not applicable to all systems.

For example, we may need to lay a branch cable at T (Fig. B) to another sub-station. This cannot be done on the author's system

because there would be opposed currents through the ends of the interconnector which would trip the relays *d* when working under normal conditions. In these instances Dr. Garrard's system has limitations where in comparison the Merz-Price has none. Mr. Clothier.

One of the great features of the Merz-Price gear is that it works on complicated networks; we may have ring mains, loops, and tees, and in every case we get absolutely instantaneous isolation of a faulty section without the interruption of supply to sound sections. We have had practical demonstrations of that; it is not a test-room development. As an instance, only recently a 20,000-volt joint box developed a fault, and was simply scattered to pieces, but the section was instantaneously isolated without interruption to the consumer's supply.

I would like also to show how a saving in the capital invested in the cable network can be obtained by the use of this system. For example,

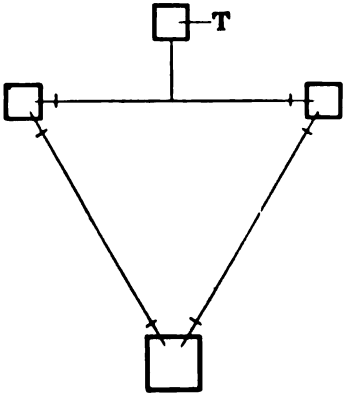


FIG. B.

assuming a power station feeding, say, five sub-stations, the ordinary system is to run duplicated cables from the power station and calls for five pairs of cables starred out. The practice has been to have overload relays with inverse time limit at the power station ends and reverse relays at the sub-station ends of the cables. Now, that method of protection suffices subject to the limitations already stated in regard to time limit and reverse relays. But with the Merz-Price system we may take those five sub-stations and join them up to the power station in a complete ring main. Roughly, the saving in capital expenditure on the feeder cable—using main cables five times the size of those required for the other system—is about 25 per cent., a saving that more than compensates for the extra cost involved by the pilot cable. Not only that, but we have a good strong cable for our ring main which is more mechanical and reliable than the smaller cables used for the duplicate feeder system.

Mr. Clothier.

Thus in many ways the Merz-Price system enabled the supply undertakings to connect consumers in a manner which was impossible under other systems, and I think it would surprise many people to know what a very large network has been developed by the aid of this gear. The network connects up in one solid, parallel running, system—the main and several smaller power stations, with numerous sub-stations (both static and rotary), covering an area of several hundred square miles.

Mr. Welbourn.

Mr. B. WELBOURN: I should like to point out that Fig. 11 is incorrect, and that in practice a complete metallic circuit, and not an earth return, is used; and for this reason it is important that the pilot wire circuit should be earthed at one end only, because when a breakdown occurs on any part of the network there is a risk that the earth-current caused thereby may tend to flow through the pilot cores and operate the relays on a healthy cable if there is an intentional earth on each end of the pilot circuit.

With reference to the statement on page 604 about multi-core cables, Merz and Price do not use, and have never tried to use in practice, a system of pilot wires laid up in one cable with the main conductors. In all cases they have laid a separate 3-core pilot cable with each 3-core feeder, and have been gradually installing this system on this plan since 1904. The author's two objections to the Merz and Price proposals seem to me, therefore, to disappear. It may be well to state that Merz and Price began their experiments in 1902, and by 1904 were so assured of the results they could obtain that they commenced systematically laying pilot cables with all new feeders. A large amount of money has been spent in its development, and now practical experience has shown its unfailing reliability, with the result that there are at present seventy individual feeders totalling about two hundred miles of cable and about fifty sub-stations containing some 50,000 k.w. of plant protected on the networks controlled by Mr. Merz, and there has been no case of faulty operation to date. A very extensive experience on the large networks under Mr. Merz's control has shown that all the old systems for the protection of any interconnected network are the cause of endless trouble, and even on a small system where there is no interconnection, but where duplicate cables are used and where more than one supply is given in series, it is extremely difficult, and very often impossible, to get the old style of gear to discriminate properly.

In the earliest stages of development in Newcastle down to about 1905 Mr. Merz tried nearly every make of overload and reverse-current relay then in existence, and soon was forced to the conclusion that it was impossible to discriminate with more than two, or at the most three, overloads in series under the conditions which exist on the high-tension network at the moment of short circuit, and that reverse-current relays are very erratic in action when surges take place—that is, they trip just when they are not wanted to.

With such complicated networks as those of the Newcastle and

County of Durham Companies it would be hopeless to attempt discrimination by any other principle than that of balanced gear. The feeder cable systems are of every possible description :— Mr. Welbourn.

1. Those fed from one end.
2. Those fed from both ends as interconnectors.
3. Branches taken off feeders by direct T joints.

The Newcastle engineers have worked very hard at this problem, and can now claim that they have the only large installations of well-tried and perfected protective gear, and that they could not do any automatic control worthy of the name unless they had this balanced gear. On the northern systems there have been a number (about twenty in all) breakdowns on cables and transformers due to known causes, and the faults have in every case been isolated without dislocating the supply on the healthy sections and without shock being noticeable at the power station. It is fair to claim that this highly satisfactory result can only be obtained with this balanced gear, which operates instantaneously and is especially valuable on circuits involving synchronous plants. It is of the utmost importance to note that when the failures occurred the only sections which were isolated were those containing the faults, and the balanced protective gear on adjacent healthy feeders was quite unaffected. The whole point is, that there never can be any question of the gear failing to operate on a faulty section; there is no disturbance of healthy sections, and at the same time it operates instantaneously.

Unless I misunderstand Dr. Garrard's proposals, his electrically interlocked reverse relay necessitates a time-limit element, and I do not gather that he claims instantaneous isolation of a faulty interconnector cable. This seems to be a decided disadvantage on any system containing synchronous machinery which might be thrown out of step.

To sum up the case for the Merz-Price gear :—

1. It discriminates with absolute certainty; that is, it is certain in its action in isolating faulty cables, transformers, or other plant, and is inoperative with equal certainty on healthy sections.

2. It is suitable for use on all possible arrangements of cables, whether these comprise separate feeders or form interconnectors, or consist of branch cables without switchgear at the points of junction.

3. It is as instantaneous in action as it is physically possible for any cut-out to be.

4. The apparatus is of the simplest possible character, and needs only very slight occasional attention to keep it in perfect working order.

Mr. J. G. STATTER: As a maker of and experimenter with relays, I agree with the author that the solenoid dashpot form of time lag is more or less useless for the reason that it "climbs up its setting," whether it is in the relay form or applied directly to the trip coils of circuit breakers. Mr. Statter.

Mr. Statter. With my form of sucker control a solenoid or electromagnet is quite suitable because of the entire absence of back-lash, or slip, but magnets or solenoids used in combination with bellows or dashpots fail because a certain amount of movement is allowed by the checking mechanism before it exercises any appreciable control. The movement that I have called "back-lash," or "slip," allows the core, or armature, to close up the air-gap that limits its power, or, in other words, to gain power at a given current.

A time lag to control a solenoid or electromagnet must be one that does not allow movement to commence, and not an appliance for retarding movement after it has commenced. Solenoids generally, however they are controlled, are not ideal for use with relays or circuit breaker trip coils when selective action is required. Their power increases directly with the current flowing through them, which is not what is wanted.

It is a better plan to abandon solenoids, and to design an electromagnet that attains its maximum power with a given current, and thereafter gains but little with increase of current. I prefer to use such a form of magnet in combination with my sucker time lag where selective action is desired, and the three curves shown are plotted from tests made with a relay constructed on these lines.

I feel grateful to the author for calling attention to the laxity of description which contents itself by referring to a time lag as an instrument designed to give a certain number of seconds delay. Such a description conveys no meaning, except when applied to that form of apparatus which gives a constant time lag for all overloads, which form I think I may dismiss as obsolete. The description of a time lag to give a certain number of seconds is, however, frequently the only information given by an intending user of the inverse time-element form. Specifications for time lags should state (1) the number of seconds required at a given overload, and (2) also the requirements under conditions of short circuit. The first statement needs no amplification. As to the second, perhaps I should explain that relays, or circuit breakers, provided with time lags and intended for use at generating and sub-stations, and, in fact, all breakers in series with one another, which are desired to come out in some definite order, must have their time lag so arranged that there still remains a small fraction of time lag even under short circuit conditions. On the other hand, circuit breakers for some purposes—such, for example, as the protection of motors—are better arranged to act instantly at a predetermined overload, say two or three times the normal working load of the motor. A circuit breaker provided with time lag of this description can easily be arranged to give as much as ten minutes' delay with a 10–20 per cent. overload, as may be deemed advisable, and yet have no lag at all when the overload reaches 100 per cent. An arrangement of this sort is obviously preferable to the use of time lags giving some lag with six or seven times the full load. Under such conditions it is probable that both commutator and brushes would suffer damage in the case of a

direct-current machine. My excess device can be arranged for either conditions. Referring to the curves shown in the diagram, Fig. C, it will be seen that there is an appreciable lag with six times the full load, and that, although the experiments have not been carried further than this point, it is probable, from the inclinations of the curve, that some lag will remain if the load be increased to twelve times the setting load. The curves shown correspond to those given by Dr. Garrard in Fig. 15, but whereas in Dr. Garrard's figure the settings for

Mr. Statter.

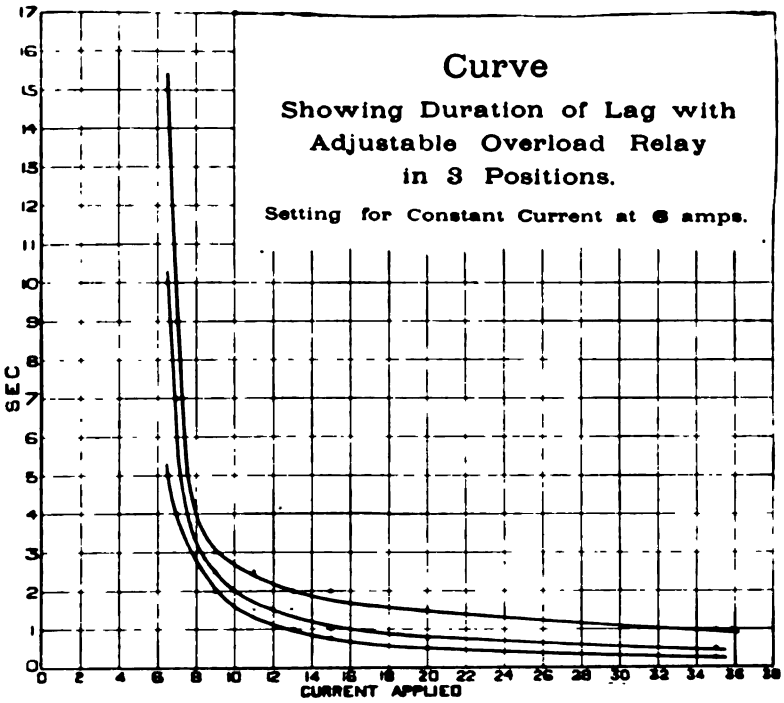


FIG. C.

each were different, the curves shown in my diagram are all taken with the relay set at 6 amperes, or under much more arduous conditions, and it will be seen that the selective order is preserved throughout. It would have been interesting to know what would have been the result of increasing the overloads in Dr. Garrard's experiments and continuing the curves to much higher readings than are shown in Fig. 15. It would seem from the direction taken by the first two curves that there is some possibility of their meeting, in which case selective action would be at an end. I should have expected rather better results from an induction type. I quite agree with the author that relays arranged for selection action should have definite positions for the setting of the time

Mr. Statter. lag curve. In the particular apparatus made by my firm the relay form of time lag is adjustable as to length of lag by means of three or four definite positions. In order to move from one position to another the use of a screwdriver is necessary. The positions are labelled 1, 2, 3, and 4, to enable the engineer to give instructions readily regarding the setting of such relays as may be required in accordance with the position they occupy on his system of mains. The adjustment for current is quite an independent one, and may be locked if desired. Referring to Fig. 8, it is unfortunate that the author has plotted the percentage of load required to operate the relay in watts; this is not what we wish to know. It is value in current that an engineer is concerned with in the case of a reverse-current relay. If current values are plotted instead of watts, the results are quite different, and appear to show that the particular wattmeter movement described by the author is not desirable in cases where a reduction in voltage exceeding 50 per cent. may occur. In fact, taking into consideration phase displacement, the reverse current might reach considerable dimensions on a reduction in bus-bar voltage of less than 50 per cent. before such a relay would act.

Mr. Wedmore. Mr. E. B. WEDMORE: I hold no brief for the defence of the polyphase relays referred to in the beginning of the paper, but I would like to point out one feature which may be argued in their favour. One has to distinguish between an overload on plant and a short circuit due to a faulty condition. An overload on a 3-phase system will ordinarily occur on all three phases. (Of course there are systems to which that does not apply.) A fault which occurs on all three phases is probably so serious that the sooner it is cut out the better. A fault that occurs on one phase may be only a momentary fault, and it may be argued that there is an advantage in having a device set to come out at a higher current on such a fault than on an overload.

Turning now to the solenoid relay of the bellows type referred to in paragraph 4 of the paper, this device, if I remember right, has been the standard device for its purpose of one of the largest manufacturing concerns in the world for about seven years—a concern which owes its position primarily, I think, to the quality of its engineering. I have found an opportunity of checking the test results given on page 591 applying to this device, and I find they are substantially correct. But the rating given by Dr. Garrard to this device is an altogether spurious rating. The rating given by the makers is 3½ amperes continuous load. If the device be set to operate on generators of normal guarantees, even at a materially lower setting than that corresponding to the author's figures, it will recover itself at a current which is above the lowest current which the generator ought to be allowed to carry. I do not know what more can be required of the device.

Referring to the fuse-shunted trip coil, I take a particular interest in this device. It is suggested in the paper that it is not possible to obtain discriminating action with this device. We are told that small changes of the current setting affect the time element enormously. It seems to me

Mr. Wedmore.

that is exactly what is required to obtain discriminating action; in other words, one is able to obtain material control of the time element without making material changes in the current setting. In another place it is suggested that we might use fuses of different materials to attain the same end. At one time I made a number of fuses of different materials.* The supply created a small demand at first, but now only the standard article is called for. There is no demand for a fuse of a second material, because the standard fuse has been found to answer all the requirements of service. Several of the largest London electric supply companies are employing this device very extensively. They are companies that can afford to pay a good price and get the best article. I do not suppose there is any time-limit device in this country at the present time that is protecting the supply of more power than this time-limit fuse or filling the requirements more satisfactorily.

Turning now to the remarks relative to cross-connected current transformers, the same arguments might be used for this method of protection as I applied to the polyphase relays. It is quite a question whether it is not an advantage to have a somewhat higher setting against faulty conditions than against conditions of overload. I do not quite agree with the figures given. An overload accompanied by a lag of 60° is not uncommon, but a fault accompanied by a lag of 60° is quite abnormal; at any rate, I may say I have never received any complaints on any such ground where this device has been installed under my supervision, and, as is mentioned in the paper, the device has been very extensively used.

Referring to the subject of reverse-current relays for service on generator circuits, I am in agreement with the bulk of what Dr. Garrard says, but I would like to raise a point with regard to the suggested setting. Presuming one decides that the complication introduced in using such a device is justifiable, Dr. Garrard suggests a setting of 10 per cent. with a time element. The time element I think is all right. I had an opportunity of testing generators under very severe emergency conditions only a short while ago, using incidentally a solenoid form of relay which filled all the conditions laid down by the author, and previously by Mr. Andrews, and we found that it was quite easy, owing to the slight oscillating action of the governors, to obtain cross-currents during paralleling amounting to, say, 40 per cent. of the normal load current. (Such currents would not show up on dead-beat switchboard instruments.) The conditions that the author has spoken of are accompanied by cross-currents having very much higher values. Now, if the relay is set at such a low value as 10 per cent. such a large time limit must be put on it, to withstand these surges, that when really severe conditions do occur there is still a large residual time limit against it. I believe in setting the reverse relay very much nearer the value which may be assigned to the largest harmless surging cross-currents which are likely to occur, and then employing

* For instance, a fuse was developed giving for the same minimum fusing current a time limit of one-tenth that of the standard at any overload.

Mr. Wedmore.

only sufficient time limit to prevent those cross-currents from doing damage. Turning now to the end of the paper, I would refer to the curve given in Fig. 16, representing what we understand were the final conditions selected for the protection of an individual feeder. It will be found to coincide closely with the curves given for the time fuses on page 591. I think a No. 34 fuse wire would just about meet the case. I suggest going the whole hog by abolishing the relay rather than the time limit.

(*Communicated*): Referring now to the problem of automatic protective devices for the remote end of parallel feeders, there are two conditions not fully met by the use of instantaneous reverse relays combined with the usual overload time-limit devices at the generating end. When a heavy fault comes on a system, especially an E.H.T. system, the resultant drop of pressure will be followed by heavy currents feeding back from sub-stations with running machinery. Multiphase induction motors even will sometimes feed back, and synchronous machinery may be depended upon to do so. This results in the complete disconnection of sub-stations having sound feeders and machines. The time element in the operation of the automatics gives all synchronous machinery a chance to get out of step and this often follows.

Raising the setting of the relay may make matters worse, as it inevitably interferes with its operation on the heaviest faults accompanied by sudden voltage drop.

The system of interlocked relays described by Dr. Garrard may be extended to cover the above case, the interlock being employed between discriminating relays installed at either end of each feeder. The interlock should be operative if current is either forward or reverse at both ends at once. The device is then proof against surges and no time limit need be employed.

I believe I was the first to design an alternating reverse-current relay operated by current only and independent of potentials. The introduction of the pilot wire principle by my colleague Mr. Clinker has greatly simplified the problem, and I am strongly of opinion that there is at present no discriminating system not employing pilot wires which could be recommended for protecting the supply of electricity in bulk to London.

Mr. Andrews.

Mr. LEONARD ANDREWS: If time had permitted I should have liked to have contributed to the discussion on each section of this paper, but as it does not I will confine my remarks to that portion dealing with discriminating apparatus. One or two previous speakers have very kindly referred to some of the work I have done in this direction. I should like to go back still further and give credit where credit is due, namely, to Mr. John S. Raworth. It was Mr. Raworth who, sixteen years ago, first drew attention, almost in Dr. Garrard's words, to the mistake of using excess current circuit breakers between generators, feeders, and transformers, and the busbars they are supplying. I had the good fortune to be one of Mr. Raworth's assistants at that time,

Mr. Andrews.

and he so hammered this principle into me that I have been trying to hammer it into other people ever since, until some of my friends have been unkind enough to suggest that I am a bit of a faddist on the subject. I should like to say that generally I agree almost entirely with the author's remarks. I am inclined to think with him, for instance, that it is better to use single-pole relays rather than compound relays. I also think that if engineers can be induced to insert a relay in each phase of a 3-phase circuit — even if the neutral point is not earthed—a more satisfactory protection will be afforded than it is possible to obtain with relays in two phases only, for the reasons the author has given. There is a good deal in what other speakers have said against this, but I still feel that Dr. Garrard's arguments are the stronger in this respect. Finally, I agree with the author that discriminating relays should not cut out of circuit a generator driven by a Corliss engine, if the steam is cut off on one side of the piston. I would go even further, and say that if the steam is cut off from the entire engine there is no need to automatically isolate the plant. If, for instance, the emergency governor should be accidentally tripped, the motoring current required to keep the plant in step until the governor is reset will not be more than 10 per cent. of the full load current, and the supply of this for a few seconds will cause far less inconvenience than cutting out the plant, thereby necessitating reparalleling under difficult conditions. I now come to a point in the paper that Dr. Garrard will, I know, expect me to disagree with him on, and that is the question of dealing with the failure of a field circuit. This is a matter that Dr. Garrard, Mr. Field, and I had a lengthy argument about after my paper at Manchester in 1904. In an article* in one of the electrical papers Mr. Field says that "relays of the reverse-power type" which the author now refers to, "will operate on any reverse power down to 10 per cent. of the full load of the circuit. This is found sufficiently sensitive to protect the average generator if the field circuit be opened — the severest test of a reverse-power indicator." In my reply† I pointed out that no reverse-power relay could afford protection under such conditions, because no reversal of power takes place when a field circuit is opened. I gather that Dr. Garrard now admits that to be a fact, for at the bottom of page 597 he says: "Provided the set remains in synchronism, and the steam supply is in order, *the alternator continues to supply energy to the system*, and there is no reason why it should be disconnected from the busbars." That is where I entirely disagree with him. In arguing that so long as a machine is running in synchronism there is nothing to worry about Dr. Garrard leads me to think that he cannot have tried the experiment of opening the field of a generator running in parallel with other machines. As I pointed out four years ago, and the author now confirms, the effect of breaking the field circuit is to produce a very heavy leading current in the faulty machine, which produces an artificial field of sufficient strength

* *Electrical Review*, vol. 56, p. 43, 1905. † Ibid., p. 206, 1905.

Mr. Andrews.

to keep the generator in step. But what becomes of this leading current? The bulk of it circulates through the armatures of the healthy machines, in which it becomes a leading current 180° out of phase with the current in the faulty machine. In other words, it lags approximately 90° on the busbar E.M.F. The result is two or more generators connected in parallel, one having no direct-current field, and the other having a direct-current field which is neutralised or wiped out by the enormous reactance of the lagging current in its armature. It is bound to follow that within a very short time (with some machines almost before the switchboard attendant has time to realise what is wrong) the volts on the entire system drop down to something like zero, and synchronous motors running at the time are almost certain to drop out of step. Quite apart from the risk of interruption to the entire supply, there is considerable danger of the generator being seriously injured by the heavy leading current. It must be remembered that the entire energy that was being supplied by the faulty machine before the interruption of its field occurred will continue to be fed into the busbars as a leading current after the field has failed, and if the power factor of this current is, say, 0·1 (it may be less), the current in the armature may be approximately ten times as great as before the break of the field circuit occurred. This may be thought to be all theory, but I would like to add that there have been numbers of actual cases of breakdowns in different stations due to the breaking of a field circuit, and I think a discriminating device that does not isolate a generator when its field fails is almost worse than useless, inasmuch as it gives a false sense of security. I am very grateful to the author for giving us Fig. 8, because it enables me to run to earth a rumour which has puzzled me for a long time; in fact, I have been intending to write to the author about it. I have been told, time after time, that Dr. Garrard's instrument will operate on a reverse current of less than 20 per cent. of the full-load current even with a potential of 10 per cent. of normal. That that has not been the author's actual claim Fig. 8 makes perfectly clear, but it is what has been understood. Engineers have been accustomed to think of, and to specify, the reverse current that a device shall operate at in amperes. I have often seen specifications calling for a device to cut out at, we will say, a reverse current of 20 per cent. of the full-load current at normal potential and perhaps at cent. per cent. at 10 per cent. of normal potential. It appears that Dr. Garrard has been accustomed to express the performance of his discriminating relays in watts instead of in amperes, as is the recognised practice, and this, as Mr. Statter has already pointed out, has proved very misleading. In Fig. D I have reproduced Dr. Garrard's curve showing the performance of his relay in watts (shown dotted), and have plotted above it another curve (shown full) in which the watts are reduced to amperes. It will be seen from this current curve that the relay in question, instead of taking only 20 per cent. of full-load current with 10 per cent. of normal pressure, as some engineers have, doubtless inadvertently, been led to believe, actually takes about

160 per cent. of full-load current at this pressure — a very different result. If the same relay had been adjusted to operate with a reverse Mr. Andrews.

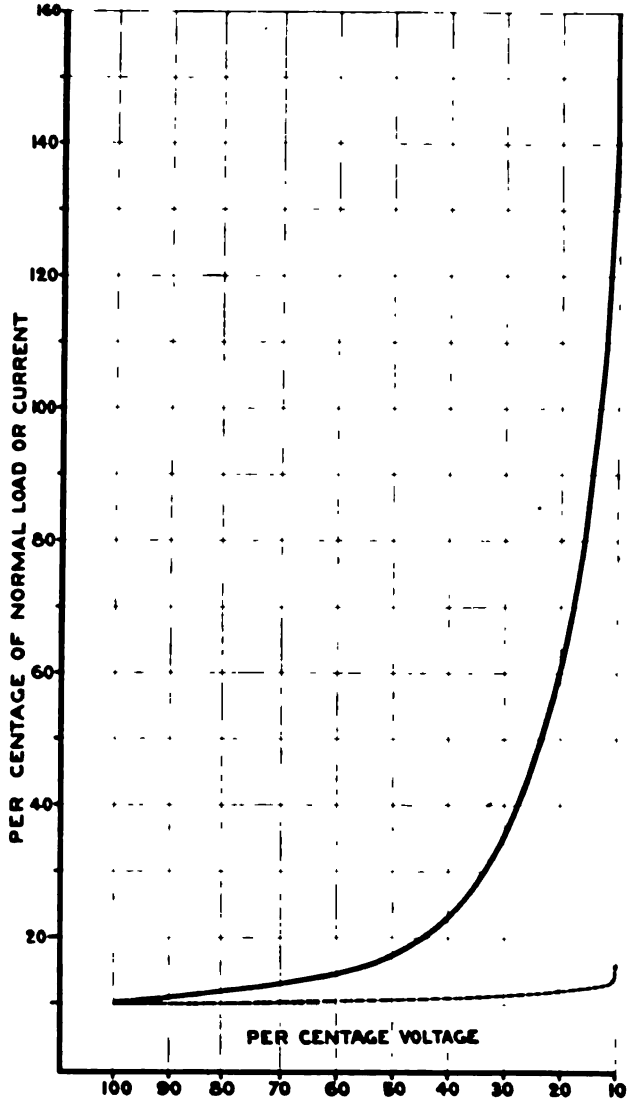


FIG. D.—Alternating-current Reverse Relay—Variation of Calibration with Voltage.

current of 30 per cent. of full-load current at normal potential, it would apparently require a current of approximately five times the full-load

Mr. Andrews.

current to operate it when the pressure fell to 10 per cent. of normal. This explains why Dr. Garrard has always advocated a 10 per cent. setting. I entirely agree with Mr. Wedmore that a 10 per cent. setting is a great mistake. I should like to see something like a 30 per cent. setting for the protection of generators insisted upon in all cases. We should not then hear, as we do now, that discriminating devices are liable to cut out when they should not do so. Those who have been working with me have aimed (and it has been a very difficult thing to obtain), at getting a relay that will operate with a reverse current of, say, 30 per cent. of full load current with normal potential, and will at the same time operate with less than full load current with a potential of 10 per cent. of normal. I am sure that a relay with such a characteristic will prove to be far more reliable under all conditions than one that takes so much more current to operate it on low potential than on normal. I hope that in future when referring to the behaviour of discriminating devices, the author will give the reverse current required in amperes, and not in watts, as much confusion will thereby be avoided. Reference has been made to the Merz-Price system. I think this is a most ingenious system, and it does what many of us who had previously worked on reverse-current devices had been unable to do—that is, it deals satisfactorily with ring main problems. I am quite sorry to see that Dr. Garrard is trying to use discriminating cut-outs for protecting ring mains. The Merz-Price system appears to be quite a satisfactory method of dealing with this, and there are so many engineering problems remaining to be solved that it seems waste of energy for an engineer to concentrate his attention upon achieving a result that has already been accomplished, merely for the sake of doing it in a different way. On the other hand, I do not quite agree with Mr. Clothier, who apparently would have us believe that the Merz-Price system is best under all conditions. The Merz-Price system is not applicable to the majority of systems already laid down, because no pilot wires have been provided. For ordinary duplicate feeders reliable discriminating devices still afford the best method of protection. Mr. Welbourn has told us what induced Messrs. Merz and Price to develop their system, and he has referred to the difficulties they experienced with discriminating cut-outs, adding that they had tried nearly every discriminating device that had been put on the market. Some years ago Mr. Merz read a paper before this Institution in which he told us that he had not been able to get a reverse-current device that would work satisfactorily. I told Mr. Merz, after that paper, that I would guarantee to supply him with a device that was absolutely reliable; but so far as I know Mr. Merz has never tried one of my devices. If he has ever tried one, it must have been one of those that Mr. Wedmore says I held a *post mortem* on some years ago. We have often endeavoured to persuade him to do so, but for some reason that up to now we have been unable to understand he has fought shy of our devices. Can it be that he realised that if he had consented to carry out the tests we asked it would have been impos-

sible for him to say in the future that he had never been able to get any device to work satisfactorily other than his own? Those speakers who have been singing the praises of the Merz-Price system have referred to various cases where it has worked satisfactorily, as if such performance was something remarkable; but we had numbers of cases of our devices working satisfactorily and never failing years before Messrs. Merz and Price commenced to develop their system. Some of the members may remember that in 1902 a large number of engineers and others visited Hastings to witness a number of experiments demonstrating the complete protection of generators, transformers, and feeders by discriminating cut-outs. One experiment consisted of driving a nail into a live 2,000-volt feeder supplying current to a sub-station a mile from the generating station, the discriminating devices at the end of the feeders reliably isolating the fault without interruption to the supply. It is unnecessary to say that I should not have done that if I had not felt very certain of what we could do. That system has never failed, and there is no reason why it should do so any more than that the Merz-Price system should fail. Mr. Andrews.

Mr. K. EDGCUMBE: There is one point I should like to raise, and that is that nearly all the author's curves of time lag stop at about three times the full load, a matter to which Mr. Statter referred. The important question is, What happens on a dead short circuit? In one well-known type of induction relay (made by a firm not a hundred miles from Manchester) a damping magnet is used for varying the time lag, its position on the damping disc being altered according to the time setting required. The result is that first-rate curves are obtained at small overloads, as shown by Dr. Garrard's figures; but, unfortunately, when the overload is fairly large the disc rotates at synchronous speed, quite irrespective of the setting of the magnet. Consequently all the time-lags are the same, so that two relays in series, one set for 5 seconds, and the other for 10 seconds, may go off in the reverse order. It seems to me essential that the time lag should be independent of the breaking force; that is to say, the mechanism should be set in motion, and before making contact should move through a distance depending on the time setting. Mr. Edgcumbe.

The only other point that I had wished to consider was in connection with reverse relays, but it has been dealt with by previous speakers. I feel it to be essential that reverse relays should be reverse-*current* relays rather than reverse-*power* relays. It is the current that does the damage, not the power. I do not think any one would use a wattmeter relay on a direct-current system, and in just the same way the alternating reverse relay should be made, as far as possible, independent of the pressure, except, of course, as regards its direction.

Mr. BERNARD JENKIN: I think one very important point has not been touched on in this paper, or by any of the speakers to-night. Dr. Garrard states on page 599 that the reverse relays must be set, at the sub-station ends of the feeders, sufficiently high to deal with the synchronising or hunting currents between the sub-station motors and Mr. Jenkin.

Mr. Jenkin. the power house generators. I think one has to go a good deal further than this. Where there are a number of motor-generators in a sub-station, their power of generating current by their inertia, or flywheel effect, is so great that one has to treat the sub-station as if it contained as large generators as the power station. Many of the troubles with reverse-current relays can, I think, be explained by taking into account the power that can be generated at the sub-stations in this way and returned to the power station.

In Fig. 10 the interconnector between two sub-stations is provided with a pilot wire, so that current can flow in either direction without disconnecting the cable. The feeders between the power house and the sub-stations should be provided with pilot wires in the same way, otherwise the reverse-current relays at the sub-station ends of the feeders will open at once on a short-circuit or excessive load at any point of the system.

We have constantly found that not only do the reverse-current relays on the feeders open in this way, but that the maximum cut-outs on the motors at the sub-stations open, and also the maximum cut-outs on the feeders at the power station. In a system such as shown in Fig. 10, but with the interconnector disconnected, it frequently happens that one sub-station will, by generating power, feed back into the power house, and from the power house into the second sub-station, when a fault or short circuit occurs at the latter point.

There is one other point I would like to refer to, and that is that with a time limit one might possibly obtain what is wanted by going a step further than Mr. Statter has gone, as shown in his diagram, namely, by using an *inverse* time element which would act instantaneously on short circuit, but instead of opening the switch would bring into action a *fixed* time limit, which could be set with absolute certainty, to open the main switch. The fixed time limit could be a very small fraction of a second, but it would make quite certain that maximum cut-outs connected in series would open in the desired order on the occurrence of a short circuit. At present cut-outs connected in series usually all open on short circuit, as the setting of the time element cannot apparently discriminate except at moderate overloads.

Mr. Orton. Mr. W. P. J. ORTON and Mr. G. NORTH (*communicated*): Referring to the second paragraph of Dr. Garrard's paper, it would be interesting to know further particulars of the polyphase wound relay with the single moving element, as this design would not appear to be in such common use as the author states.

We do not think the author's remarks on solenoid relays are altogether correct. No doubt there are relays of this type which can be made to float in the manner described; but, if the movable iron plunger and the pole-piece to which it is attracted are properly designed and other mechanical details correctly proportioned, a solenoid relay can be made to work with practically no danger of floating. It is obvious, of course, in both the solenoid and disc types of relay, that if the overload comes on again in such a short space of time the mechanism cannot reset

itself, then the relay will operate with a very short time limit in the second case. This, however, is in our opinion an advantage, as an intermittent short of this description should be disconnected from the circuit with the least possible delay. Mr. Orton.

By the disc type of relay referred to above we mean the relay acting on the induction principle in which a disc is caused to rotate between the poles of an electromagnet by means of the eddy currents set up in the former.

We are quite in agreement with the author's remarks as to a time limit being obtained with trip coils shunted by fuses. This is a very cheap and satisfactory method for controlling motors or small subsidiary circuits, but it would be bad practice to install such a device on a network of feeders.

Referring to Fig. 8, we would point out that the author's description would lead the reader to believe that the alternating-current reverse relay described acted on a drop in voltage without a corresponding increase in current, but on referring to the above-mentioned figure it will be noted that the ordinates are represented in watts—that is to say, that since the relay acts at 10 per cent. of full-load watts with full voltage, it will act about 10·5 per cent. of full-load watts when the volts have dropped 40 per cent. This, therefore, means that the current will be practically doubled, and is the result which would naturally be expected with a wattmeter relay.

We note that the author's method of protecting interconnector cable has the advantage over the Merz-Price system of employing only one pilot wire ; but, since from Fig. 8 the reverse relays proposed are dependent solely on the actual power in watts passing through them, it would be possible when the sub-station voltage fell to a very low value that the current required to actuate the relay would be so great that the inverse time element maximum relays in series with the fault would act before the relays in question, thus shutting down the whole or part of the supply without isolating the faulty inter-connector.

From Fig. 10 we notice that the author recommends time element maximum relays with varying time element in series, and whilst we agree that this is the best method of protecting distribution in sub-station systems, we would point out that it is the subject of Mr. Stillwell's Patent No. 25,422 of 1899.

Mr. H. Bevis (*communicated*): With regard to the discussion on Dr. Garrard's paper, I can quite confirm the statement that 3-phase relays are not good practice, and that three separate relays should most certainly be used. Mr. Bevis.

I think that the solenoid relays which Dr. Garrard tested must have evidently been of inferior design, as I notice that they have 11-volts drop, whilst there is no difficulty in making relays to work with a much lower voltage drop. I note also he points out that a detrimental feature of the solenoid relays he tested was the variation in the magnetic reluctance of the circuit due to the different positions of the plunger. It may be that the relay tested has a return iron circuit,

Mr. Bevis. whilst if the circuit is mostly air, the flux is rendered proportionate to the current. Relays can be made with the return circuit of air, in which case the defects mentioned above would be greatly minimised.

I do not agree with the criticisms on the solenoid relay put forward by Dr. Garrard; my experience is that they are very reliable owing to the fact that they have no revolving parts, pivots, or axles to stick; in fact, there is little or nothing to get out of order, and a good deal of power is obtained. The overload and time adjustment of a solenoid relay can be made quite independent just as readily as any other types, whilst the cost of manufacture is very much less.

Another point in connection with the solenoid type of relay is that it does not require such careful handling on the part of the station engineers as the induction type, which, at the best of times, is a somewhat delicate instrument.

An important point that is entirely overlooked by the author is, that a reverse-current relay with a wattmeter movement lacks all provision for differences in power factor; that is to say, a reverse-current relay set to work at a given current with a power factor of unity requires twice the reverse current at a power of 0·5. I do not know whether the author has any suggestion or device for providing for this, but otherwise this would seem to be a most important defect with the use of reverse-current relays.

I do not consider it good practice to have a time limit on a reverse-current relay, because the small reversals that take place during synchronising are negligible; on the other hand, what is required is a device that takes care of a big reversal, and when such a reversal does take place there should be no time limit intervening, and it should be instantaneous.

I would say, in conclusion, my opinion is that the present tendency is that the central station engineer is somewhat inclined to put in too many automatic devices. Taken in moderation, they are essential for central station work, but multiplication of such devices is not to be desired, and only the smallest number necessary should be installed.

Dr. Garrard. Dr. C. C. GARRARD (*in reply*): Mr. H. W. Clothier condemns the use of the maximum current inverse time element and reverse power system of protection, and states that the Merz and Price system is the only perfect one. Now, I quite admit that the Merz and Price system, when a pilot wire is essential, as, for example, for the protection of an interconnector cable, is a very good system. It is, however, not so simple as it looks, as can be seen from a comparison of the original patent specifications and the descriptive publications recently issued by the manufacturers who supply this gear. The great disadvantage of the Merz and Price system is the large number of pilot wires. For each 3-phase interconnector three pilot wires are necessary. The proposal to extend this system of protection to all feeders, all transformers, and all other apparatus, will result in a tremendous complication of the controlling gear. In my opinion, a pilot wire should only be used when it is absolutely essential.

Dr. Garrard.

It will be noticed that the system I have described in paragraph 16 only entails the use of one pilot wire under all circumstances, which is certainly an advantage, as it simplifies the gear very much. For the protection of ordinary feeders, I think the standard system of an inverse time element maximum circuit breaker on the outgoing end, and an instantaneous reverse relay at the incoming end, is quite satisfactory. Many hundreds of feeders are protected in this, or a very similar, manner, and when the system is properly carried out, and the circuit breakers correctly graded, satisfactory results are obtained.

Mr. Clothier refers to alternating reverse "current" relays. I think the correct designation should be alternating reverse "power" relays. No doubt, in the past, many unsatisfactory devices have been put on the market, and I would think that the bad results obtained by Mr. Merz were obtained with apparatus designed on wrong lines, which has brought the system into some discredit. The object of my paper is to show how the system should be carried out in order to secure successful results. Mr. Clothier raised objections to my system for interconnector protection on the ground that (compare Fig. 9B) should the feeder connecting S_1 to G be broken, then the interlocked reverse relays would not protect the cable S_1 to S_2. In reply, I would point out that the system is specifically for the protection of interconnectors. In the case Mr. Clothier mentions, the cable S_1 to S_2 is not an interconnector at all, but simply an on-going feeder. Under normal conditions, however, the cable S_1 to S_2 is an interconnector. Should now it be desirable to run with the cable S_1 to G broken, then, whether the protective arrangements on the interconnector will be operated or not, will depend upon whether or not power can flow back into the interconnector from S_1. This will depend upon the class of machine running in the sub-station S_1. If the sub-station S_1 cannot feed back power into the interconnector, then when the cable S_1 to S_2 is used as an on-going feeder the pilot wire should be disconnected, and the other protective devices on the system relied upon for protection.

I would point out that it would not be safe to rely upon the Merz-Price system alone for the protection of all feeders. With this system the feeders are not protected against plain overload. Likewise, the protection given only extends up to the current transformers, which are generally and properly installed on the line side of the switches. Should now a switch break down, or a short circuit develop between sub-station busbars, or on the wiring of the sub-station switchboard, the Merz-Price system will not save the situation as such a fault simply overloads the cable and does not unbalance the protective devices, so that they experience no tendency to operate. I think, therefore, that maximum circuit-breaking apparatus is a necessity in addition to the Merz-Price system.

Again, if this system be the only one adopted, the circuit is not protected against overloads in any way whatever. I think it is as necessary to protect the cable against overloads as it is to protect a generator or motor. With the Merz-Price system only in force a cable could be

Dr. Garrard

overloaded until it was burned out and yet not be disconnected from the system.

Mr. Clothier also showed a line of five sub-stations fed by one ring main, and two feeders only for all the five sub-stations. I think this is carrying matters rather too far, as, it will be seen, a simultaneous breakdown on the two feeders will result in all the five sub-stations being shut down.

Mr. Welbourn also spoke of the Merz-Price system, and the remarks I have made in answer to Mr. Clothier will also apply here. I am pleased to hear of the success of the system, and that in twenty cases it has been known to operate satisfactorily. Of course, this is rather a limited experience, and not anywhere nearly as large as the experience I have had with the maximum and reverse circuit-breaker system of protection. I would say that the interlocked reverse relay described in paragraph 16 does not operate quite instantaneously.

Mr. Statter refers to the curves given in Fig. 15, and thinks that these might cross if the currents through the relays themselves had been plotted. This, however, is not so. The three curves in Fig. 15 are not intended to be calibration curves of circuit breakers in series with each other, and do not correspond to the curves given by Mr. Statter in Fig. C. They (Fig. 15) are intended, on the other hand, to be calibration curves of circuit breakers controlling outgoing feeders, such that the sub-station motor circuit breakers (calibration curve, Fig. 16) will always open before the feeder circuit breakers. Which of the three curves in Fig. 15 will be used will depend upon the normal carrying capacity of the cable. The curves in Fig. 15 illustrate how with these relays the current calibration is independent of the time calibration. If Mr. Statter will take the curves given in Figs. 15 and 16, and divide the horizontal co-ordinates by the ratios of the current transformers used, he will find that he will obtain a similar system of curves as exhibited by him, and they will never cross one another. Of course, when maximum inverse time element circuit breakers are in series with each other, when a heavy short comes on, the order in which these circuit breakers operate depends upon the minimum time. The induction-type relay, after a certain current is reached, gets into synchronous speed and never goes any quicker; thus it always has a true minimum time which can be used for grading purposes. This is a property shared, as far as I am aware, by no other type of device.

Mr. Statter has misunderstood the reference to 50 per cent. in paragraph 10. If he will refer to the paragraph again he will see that I have pointed out that the reverse relay described does not vary materially in its calibration down to 10 per cent. of the normal voltage. As a fall of potential lower than 50 per cent. of the normal voltage, due to a failing generator, is not to be expected, it will be seen that there is a large margin of safety.

I am glad to hear that Mr. Wedmore is discarding the scheme of connections shown in Figs. 5 and 7. Mr. Wedmore also states that when a fault occurs on a 3-phase feeder it always affects two phases

at least. I can well believe this if the system of protection had been as given in Fig. 5. An earth, for instance, on a 3-phase feeder very often only involves one phase first. If the feeder be not disconnected, however, the other phases are very soon involved also. With a proper system of connections, on the other hand, the feeder is cut off without the other two phases being damaged at all, and this is very much more satisfactory than allowing the fault to spread to two or more phases before the protecting apparatus can come into operation. Dr. Garrard

As regards the fuse-shunted trip coils (Fig. 4), I regard it as absolutely essential that the time calibration and the current calibration of a circuit-breaking device be capable of adjustment independently of each other. Mr. Wedmore states that this can be done by using fuses of different materials. I do not think, however, this is correct. A paper recently presented to this Institution by Professor Schwartz and Mr. James on "Fuse Phenomena" throws some light on this question, and in the communication I made to that discussion I have shown that it is impossible to adjust satisfactorily fuse-shunted trip coils independently of the current calibration by altering the material of the fuse wire (compare Figs. 21 and 23 of Professor Schwartz and Mr. James's paper, *Journal*, vol. 41, pp. 68–69).

As regards the setting of reverse relays on generators, I have found the 10 per cent. setting to be satisfactory. With this setting the maximum current which can flow into the generator on a reversal of energy can never be so large as to be dangerous, that is, never more than about three times full load under the worst possible conditions. Of course, if the reversal of energy into the generator exceed 10 per cent. considerably, the time element is very small. The residual time element with the reverse relays I have used is about half a second. It can be made less if desired, though I do not think it advisable.

I certainly agree with Mr. Andrews that credit should be given to Mr. Raworth for the early work he did in this connection. Mr. Andrews is strongly of the opinion that the reverse circuit breaker on the generator should cut the generator off if the field current of the generator fails independently of the direction of flow of power between the machine and the busbars. I do not agree with this. Also, I do not think there is any need to agree with it, as, if the failure of the field current is a thing to be guarded against at all costs, obviously the simplest thing to do is to put a very simple relay in the field circuit of the generator, which will have the effect of opening the main circuit breaker when the field current fails. Such an apparatus would only cost a few shillings. In my view the reverse device on a generator should be a reverse-power device, and should only cut the generator off when the same has ceased to fulfil its proper function, that is, to deliver power to the busbars.

Mr. Andrews refers to reverse "current" devices. For alternating circuits, however, this is a very loose term, as, in order to give it a definite meaning, one must give the power factor of the current. In my view the reverse-power device, if set for 10 per cent. of the normal

Dr. Garrard. full load of the generator, will cut the generator off when it should be cut off, and under no condition would it cut it off when it should not be cut off. This is a characteristic not common to any other type of reverse device with which I am familiar.

The curve which Mr. Andrews has deduced from Fig. 8 is very interesting, but I do not quite see the point of it. All it shows is that with a 10 per cent. setting, and a voltage down to one-tenth of its normal value, the current necessary to operate the relay would be about 50 per cent. above full-load current. This is, of course, nothing at all serious, and is perfectly obvious. The reverse relay in question is a wattmeter, and for a certain watt setting, if the volts are low, the current is high, and *vice versâ*. The point is that with a 10 per cent. setting the size of the current can never be dangerously large. It would greatly interest me if Mr. Andrews would publish a calibration curve of his reverse "current" device taken under the same conditions as that in Fig. 8 of the paper.

Mr. Andrews is, of course, right in his interesting exposition of what occurs when the field of a generator, running in parallel with others, is broken, except that I do not think the busbar voltage can drop to zero; I think a drop of 50 per cent. would be nearer the mark. The only difference between Mr. Andrews and my own views on this question is that Mr. Andrews thinks that a reverse device should not only operate on a reversal of power, but also on forward power with a leading current. This has the disadvantage that, under certain conditions, although there will be a true reversal of power, the device will not operate. A true reverse-power device will only operate on power reversal. It is a pity to spoil this simple action by endeavouring to guard against the failure of the field without a reversal of power. This could easily be met by the very simple field-circuit relay I have suggested above. The very fact that this very obvious course has never been adopted shows, I think, that the danger to which Mr. Andrews refers is more hypothetical than real.

As regards what Mr. Andrews says as to the "recognised practice" of expressing the performance of alternating discriminating relays in amperes, this may, or may not be, correct; but, at any rate, it is a bad practice, and one that I have been agitating against for a long time. The performance of an alternating-current device cannot be expressed in amperes unless the power factor be given likewise. I am an advocate of simplicity in these matters. If, as I contend, the direction of flow of power in the cable joining the generator to the busbar is the criterion of action, or inaction, of the reverse device, then, obviously, the calibration of the same should be expressed in watts. In spite of what Mr. Andrews says, I can say that practical tests show that the wattmeter relay I have mentioned acts with actually less current at low potentials than some other reverse "current" devices with which it has been compared. This not by reason of any difference in principle, but simply because a wattmeter relay can, *ipso facto*, be made to have a more delicate setting than solenoid and such types of relays.

As regards Mr. Edgcumbe's remarks as to the times of the

maximum relay on a dead short circuit; as stated before, if the relay is constructed on the induction principle, there is a definite minimum time corresponding to synchronous speed. This minimum time can be varied at will on an induction type relay by altering the length of travel of the suspended weight. Dr. Garrard.

I am exceedingly interested in Mr. Bernard Jenkin's remarks regarding the extremely large power which he has found can flow back from sub-stations when a fault develops on a cable system. I take it this was with synchronous motor sub-stations. As I have said in the paper in paragraph 12, the feeder-end reverse power relay should be set proportionately higher than the reverse power relay on the generator. The precise value at which it should be set must depend upon circumstances. Possibly, in some cases, it might be set as high as 100 per cent. of the normal full load of the feeder.

In reply to Messrs. Orton and North I would say that the polyphase wound relay has been adopted more by Continental manufacturers than by British manufacturers. Regarding what they say about Mr. Stillwell's work in 1899, his arrangement was certainly a very ingenious one, and contained some of the underlying ideas in the present system of maximum inverse time element circuit breaker protection. It might be pointed out, however, that Mr. Stillwell proposed to use a fixed time for all overloads. The present practice is to use a time element inversely proportional to the overload for all ordinary overloads, with a fixed minimum time for short circuits. Secondly, the arrangement shown in Mr. Stillwell's patent had the disadvantage that if the overload only endured for a fraction of the time element of the circuit breaker, the clock timing mechanism would go on working and would probably cause the switch to open circuit. In fact, an instantaneous surge of current would set working the clock mechanisms of all the switches in series, and probably some, or all, would be opened at the end of the times to which they are set, independently whether the overload had gone off again or not.

Mr. Bevis asks if the solenoid relay referred to in Fig. 2 had an iron return circuit. In answer, I would say that it had. I am pleased to hear of the success Mr. Bevis has had with the solenoid type of relay. I should be glad of an opportunity to test one of these. As regards the effect of power factor on a wattmeter relay, of course, the lower the power factor the larger is the current required to work it. This, however, does not matter, as the function of the device is to guard against reversals of direction of flow of power. As regards the provision of a time element on the generator reverse relay, the conclusions I have come to are given in paragraph 8 of the paper, though, doubtless, there is considerable force in what Mr. Bevis says.

The CHAIRMAN (Mr. W. H. PATCHELL): Gentlemen, I am sure you will join with me in according a very hearty vote of thanks to Dr. Garrard for his paper. The Chairman.

The resolution of thanks was carried with acclamation.

Proceedings of the Four Hundred and Eightieth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Royal Society of Arts, John Street, Adelphi, on Thursday evening, May 21, 1908, Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting held on May 14, 1908, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—
William Cramp. | F. J. G. Holden.
G. F. Pilditch.

From the class of Associates to that of Members—
John P. Gregory.

From the class of Associates to that of Associate Members—
F. W. Page. | Harvey Whittle.

From the class of Students to that of Associate Members—
W. Gillespie. | J. P. Tierney.

Messrs. Roger T. Smith and L. T. Healy were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Associate Members.

Thomas Cleghorn Baillie. | William Henry Frazer.
John Sisson St. George Cooper | J. Lustgarten, M.Sc.
Leonard Canton Morris.

As Students.

James Brander.
Edwin Arthur Corbin.
Harry Cross.
Sydney Holbrook Crow.
Francis De Lautour.
James J. Fitzsimons.
Fred James Gibson.
Clifford Higgins.
Alfred Hutt.
Alan Lee.
Thomas Brook Richardson.
Frederic John Stevenson.
Hugh Pilgrim P. Trimingham.
Frank Rowland D. Wickham.

The following paper was read and discussed :—

RECENT PROGRESS IN TUNGSTEN METALLIC FILAMENT LAMPS.

By H. HIRST, Member.

(*Paper received April 9, and read in London on May 21, 1908.*)

During the past few years a great deal of attention has been paid both by chemists and electrical engineers to the construction of metallic filament lamps for incandescent electric lighting. Ever since the advent of the Nernst lamp with its oxide filament, chemists, scientists, and lamp makers have felt instinctively that the supremacy of the carbon filament lamp was seriously challenged. The efforts made have been attended with more or less success, yet it may be news to a large number of electrical engineers of the younger generation that the metallic filament lamp is one of the oldest forms of electric lighting. In fact, incandescent electric lighting commenced with metallic filament lamps, platinum being the incandescent body. Such lamps were made long before the Edison or the Swan carbon filaments were invented. Several inventors worked on these lines, and Edison especially endeavoured to perfect a lamp in which a thin platinum wire raised to white heat by the current formed the illuminating body.

These lamps were, however, never a commercial success, because the melting-point of platinum is only slightly higher than that temperature to which it has to be raised for the economical production of light. In consequence the life of the filaments was short, and the slightest increase in the voltage, which was extremely difficult to prevent in those days, was sufficient to melt the filament. Attempts were made to overcome this defect by automatic arrangements to cut out the lamps should the voltage rise to a point likely to melt the filament.

Even in 1880 we find Edison * trying to further improve the platinum lamp. Maxim † in 1881 describes and claims a thermo-regulator designed to prevent the overheating and consequent melting of the platinum filament. In the same year Maxim ‡ described a process of producing carbon bodies for illuminating purposes which were flashed in carbonaceous vapours with a view of improving them.

It was in 1881 that the carbon filament lamp came to the front and

* U.S. patent No. 227,229, 1880.
† U.S. patent No. 247,380, 1881.
‡ German patent No. 13,383, 1881.

stopped the researches and experiments in connection with the perfection of the then existing metallic filament lamps. It was only after a lapse of nine years that the next American patent dealing with a new metallic filament lamp made its appearance—this was the Poland patent No. 432,710, of 1890, for the iridium lamp.

There were two predominant reasons for the immediate success of carbon as a glow-lamp filament.

1. It could not be melted, and in this respect had an enormous advantage over any of the then known metals. Platinum had at that time the highest melting-point of any of the then available metals which could be made into a thin wire, but this temperature is much lower than that which a carbon filament will stand for a prolonged period in a vacuum.

2. Carbon has also a very high specific resistance as compared with any of the metals then available. The question of the distribution of current was at that time of great importance, and it was even then recognised to be a difficult problem to distribute large currents at a low pressure over a considerable area.

Due to its high specific resistance carbon was found to be a most suitable material from which to produce illuminating bodies to be incandesced by a small current at a high voltage.

When first introduced the carbon filament lamps were made for circuits of 50 to 60 volts, but improvements in manufacture soon increased the standard to 110 volts. The bulk of the pioneering work in central station supply was carried out at this voltage, but it was found that as the distribution networks were extended over large areas the great cost of attaining constant voltage was hampering the spread of electric lighting. The mains absorbed such a large proportion of the total capital outlay of a supply system that it was found necessary to raise the pressure of distribution in order to keep down the cost of electrical energy to a reasonable figure.

The 3- and 5-wire continuous-current systems invented by the late Dr. John Hopkinson, and the high-pressure alternate current with step-down transformers, helped to extend the period during which 110-volt lamps could be used. In spite of these means of reducing the cost of the distributing networks and feeders, the engineers of the electric supply companies and of the municipal authorities encouraged the incandescent lamp makers to develop higher voltage lamps. As a result the 200–250-volt lamps made their appearance in the early nineties, and by the middle of that decade were adopted commercially.

Although these lamps were not as efficient as those for the lower voltages, they saved so much in the cost of distribution that the supply companies were able to reduce the cost of electrical energy to those consumers using them. These lamps have since been so far improved in efficiency as to meet all requirements, and they were officially recognised by the Board of Trade Regulations issued in 1901, which enabled the supply undertakers to enforce their use on all consumers.

Some Recent Inventions and Developments in the Metallic Filament Lamp.

When the carbon incandescent lamps were first introduced they had to compete with the flat-flame gas burners, and a glance through the earlier estimates of the comparative costs of electric and gas lighting shows that these gas burners were then considered as the standard illuminant. With the high price of electricity it was the very great convenience, beauty, and safety of the carbon lamp which enabled electric lighting to make the progress it did. As this price of electricity was lowered with extended use, the carbon lamp had to face a much stronger competitor.

The incandescent gas mantle invented by Auer von Welsbach suddenly reduced the cost of gas lighting to one-third of what it had been before. Electric lighting has survived this blow and made progress, but this progress during the last ten years has been severely handicapped by the cheapness of incandescent gas lighting.

It is worthy of note that a considerable number of gas engineers considered that Welsbach mantles would ruin their undertakings because they reduced the consumption of gas for a given amount of light by one-third. Sufficient time has now elapsed to show how absurd their prophecies were.

It is of far greater interest to electrical engineers to know that Auer von Welsbach by his invention of the osmium lamp has removed the handicap which he placed on the electrical industry. Thus what he has taken away with one hand his inventive genius has enabled him to return with the other.

The existence of incandescent gas lighting has not only had a damaging but also a stimulating influence on the development of electric lighting. The quiet peculiar radiation of the incandescent gas mantle, which, as is well known, consists of thorium oxide containing 1 per cent. of cerium oxide, has been the subject of numerous researches which have furthered the purely theoretical knowledge of radiation. Very careful experiments, especially the now famous investigations of Lummer, have shown that bodies exist which at the same temperature radiate as light a larger percentage of the supplied energy than the so-called "black bodies." The Welsbach mantle owes its high efficiency to this property.

The success of these oxides of the rare earths in gas lighting led to their application to electric lighting, as has been done in the Nernst lamp. The first English patent for this lamp was applied for by Nernst* on August 23, 1897, and in one of the claims it is stated that—

> "A body of magnesia, zirconia, or suitable rare oxide is heated to incandescence by a Bunsen gas flame or otherwise and is then kept incandescent by the passage of electric current through it."

* British patent No. 19,427, 1897.

called the "coating" process was protected by Drs. Just and Hanaman in their British patent No. 11,949 of 1905.

These fundamental patents appear to protect the processes according to which tungsten filaments can be manufactured commercially at the present time.

Before passing on to the details of manufacture, I desire to mention the patents of some other inventors. Amongst these are—

Heany (American patent No. 839,585) who proposes to use an alloy of tungsten with titanium.

Kuzel (British patent No. 28,154 of 1904) suggests the manufacture of glowing bodies from colloidal metals.

British Thomson-Houston Company (British patent No. 18,749 of 1906 and subsequent patents) describes the manufacture of filaments of tungsten with the help of volatile metals or alloys, chiefly amalgams, which could be drawn into wire. It will be interesting to watch the progress of this suggestion.

Zerning (British patent No. 2,554 of 1906) claims the use of hydrogen and nitrogen compounds of tungsten as the materials from which to construct tungsten filaments.

As far as I know, the hydrogenous compounds of tungsten have never been described by a chemist, and from the information I have been able to obtain the statement of Sir Henry Roscoe still stands. In his famous work "Elements of Chemistry" he refers to the treatment by Berzelius of tungsten trioxide in a current of hydrogen.

I understand that the result of the experiments of this famous scientist, which were confirmed by his French contemporary, Moissan, was the production of nothing but pure tungsten powder without any trace of hydrogenous compound being formed.

As Zerning's experiments were directed towards the same object, it would denote a wonderful achievement if he should have produced a result which is not described in any scientific work and which the above eminent authorities found to be impossible.

The nitrogenous compounds are well known, and it is proved that they cannot exist at the high temperature at which the filaments have to be burned. The patent description is not very clear, but indicates that Zerning intends to make use of the "paste" process, thus producing filaments containing probably carbon or carbide.

After a careful consideration of all the patents on the subject, I believe I am right in maintaining that of the multitude of processes that have been applied for and tried since the first application of the Deutsche Gasglühlicht Aktiengesellschaft and the Just and Hanaman patents, these two alone have during the last two years produced to the world commercial and useful lamps. By this I mean lamps of such characteristics as regards current consumption, life, and light as to inaugurate a new epoch in the electric lighting industry.

It has been ascertained that all metallic filaments burning at a consumption of one watt per candle have been made with tungsten filaments. If ever so small percentages of other substances are added to the tungsten, the economy and useful life of lamps with such filaments suffer immediately.

"Osram" is the name under which the Auer Company introduced the first commercial tungsten metal filament lamp.

The osram lamp is manufactured by the "paste" process, the principle of which consists in preparing from solid substances, such as the metals themselves, in the most finely divided form, a paste with binding or stiffening agents such as the gums, dextrine, and other similar bodies. Such a mass has the consistency of putty, and is then squirted through a very fine orifice in a diamond, with a pressure of several tons per square inch. The result of the squirting operation is that one obtains a somewhat moist thread, which, however, has enough coherence to be formed into filaments that do not break while being dried.

The filaments are first heated under exclusion of air and then possess sufficient strength to be held in metal clamps. They are then subjected to the passage of an electric current which raises them to a high temperature, causing the filaments to sinter. The process of sintering is carried out in gases which chemically attack all the constituents of the binding agent, without the metal being affected, so that eventually a filament of pure metal remains. This filament is dense and homogeneous, but being obtained by a sintering process it is different in structure from the still denser metal which would be obtained from a melted mass.

Auer von Welsbach* describes a method for the manufacture of an electrical illuminating body of osmium by sintering the most finely divided metal at such a high temperature that platinum would evaporate, which temperature destroys the binding material used in the manufacture of the threads. The filament so obtained withstands a very high temperature, but it is still of a more or less spongy or porous constitution; very metallic, but nearly solid. The difference of the filament of the osram lamp, which is pure tungsten metal, from the filaments of the osmium lamp, shows itself by the following characteristics. Owing to the higher melting-point of tungsten, an osram filament will stand a temperature at least 100° C. higher than the osmium filament. Their *specific resistance* and *resistance coefficients* differ and there is considerable difference in their *radiation properties*. The *colour* of the osram filament is a steel to a silver grey, whilst the osmium filament has a bluish-grey appearance.

When preparing osram filaments for lamps of 120 volts, 22 to 27 c.p., burning at an efficiency of about 1·1 watts per candle-power, taking 0·2 to 0·25 amperes, the diameter of the filaments is 0·03 mm. The jet from which this filament is squirted is, of course, much larger. As an example :—

* British specification 1,535 of 1898, and German patent 138,135.

The diameter of the jet at point of issue from the diamond is about	0·055 mm.
The thread, after being squirted, shrinks to, when dried	0·050 „
After it has been heated to a red heat under exclusion of air, it becomes a very porous filament, with a diameter of	0·045 „
When this is sintered by the passage of an electric current, which raises it to the brightest white heat, its length is reduced, and it finally shrinks down to a diameter of	0·030 „
The shrinkage is caused by the removal of the carbon and other material forming the organic binding medium, which originally amounted to of the volume of the paste.	84 per cent.
It follows that during the whole process 84 per cent. of the original volume must disappear, and the shrinkage corresponds to a linear contraction of	55 „

It is easy to alter the amount of shrinkage by selecting suitable proportions of the binding medium or by adding volatile substances which disappear on heating.

During this *heating process* the filament is fastened in clamps and placed in globes or other arrangements containing certain gases. The heating is effected by the electric current to a gradually increasing amount, and while the thread decreases in length and diameter, it at the same time allows the passage of increased currents. This is due to the sintering of the particles and also to the filament being freed from carbon, which even in minute quantities increases its resistance. The process is controlled by the operator, who has a voltmeter and ammeter to guide him. The current increases rapidly at first, but reaches a constant value within a few minutes. This is common to all sintering processes, and the same phenomena are observed with osmium, iridium, or molybdenum filaments.

The filament so obtained is elastic but brittle, that is, the osram thread, 0·03 mm. diameter, can be bent into a loop of about one centimetre diameter without breaking. After this bending it returns to its original form. Each filament is fastened on to its leading-in wires without the application of any paste.

This is carried out in the following way: The end of the leading-in wire is melted down to a small globule by means of an electric arc. This globule holds the filament securely, and the resistance from the passage of the current from the leading-in wire to the filament is negligible.

The *evacuation of the lamp* is carried out in the same way as with

carbon filament lamps. Any process, mechanical or chemical, is suitable, but it is found that any traces of the gases occluded in the tungsten filament escape much more slowly than in the case of the carbon filament. The result is that the evacuation process requires a longer time with the osram than with the carbon filament lamp.

The *other method of constructing tungsten filaments* was developed by Drs. Just and Hanaman simultaneously with, but quite independently of, the Deutsche Gasglühlicht Aktiengesellschaft. Their lamp was introduced commercially under the name "Just-Wolfram." They use what is known as the "coating process," as described in the British patents 11,949 of 1905 and 3,684 of 1906. This interesting process is carried out as follows: Ordinary carbon filaments of very small diameter, 0·02 to 0·06 mm., are raised to a bright red heat by means of an electric current in an atmosphere of volatile tungsten compounds in the presence of hydrogen. The compounds most used are the chlorides and oxychlorides of tungsten.

The heat of the filament causes the hydrogen to reduce the volatile metallic compounds, depositing the metal in homogeneous condition on the carbon filament.

A later patent discloses a process whereby three or more filaments are coated in series at one operation. After the filaments have been coated in this way, their transformation into pure tungsten filaments is carried out as follows:—

The filaments are submitted to the action of an electric current in an atmosphere of highly rarefied inert gas, such as, for example, hydrogen at a pressure of about 20 mm., until they show the clearest white incandescence. This process causes the carbon to combine with the tungsten surrounding it, forming a carbide. This change is so complete that in the resulting filament the cross-section is tubular, and no carbon can be distinguished under a microscope at the point of fracture. The filaments so obtained containing carbon (mostly as carbide) present a glittering white metallic appearance.

In the next process they are raised to a high temperature through the passage of an electric current while they are surrounded by a mixture of hydrogen and a little steam. This causes the carbon to be oxidised by the same reactions which go on in the water-gas process. The carbon may, however, be eliminated by any other method which gives a resulting filament entirely free from carbon. Further improvements of this process, first described in the British patent 11,949 of 1905, have been disclosed in the British patent 3,684 of 1906.

Drs. Just and Hanaman have also obtained patents* protecting the process of *mounting* their tungsten filaments to the leading-in wires. This is effected by means of a paste consisting of finely divided tungsten metal mixed with coal tar or gum. These paste mounts are dried and finally made red hot by any suitable means before the filament is heated in the bulb.

The supports used in these lamps are made of suitable metal.

* British patent No. 9,349 of 1906.

Exhausting is done in a manner similar to that employed for carbon lamps.

The filaments made by this process have a light grey silvery appearance and a little smoother surface than those made by other methods; in fact, they most nearly approach the appearance of a drawn wire.

Though this process is entirely different from the "paste" process, the final result in each case is a pure, sintered filament of tungsten metal. The sole difference is that the filament made by the Just and Hanaman process is tubular. As regards economy, the tungsten or osram lamps produced by either of the above-described processes have identically the same characteristics.

It has been proved that these lamps will burn for from 1,000 to 2,000 hours with a consumption of about 1 watt per candle-power, without any appreciable falling off in the candle-power. Of all the metals which have been experimented with up to now, only pure tungsten has such a life.

In economy, the result is also better than has been obtained with other filaments, thus:—

The osmium filament takes 1·5 watts and the tantalum 1·7 watts for direct current, and somewhat more for alternating.

Output and Efficiency.

In the following comparisons between the osram and carbon lamps I have adopted the Hefner candle-power in every case, as this has so far been the standard mostly used when metallic filament lamps have been discussed. At the present it is found next to impossible to try to standardise metallic filament lamps per *candle-power*. It would make the lamp commercially impracticable.

The metallic filament lamps resemble in characteristics more the incandescent gas mantle than carbon filament lamps, and there is, therefore, nothing unreasonable in demanding a similar treatment for them as is accorded to the incandescent gas mantle. The normal efficiency of both osram and Just and Hanaman lamps of all voltages is about 1 watt per candle-power. At such efficiencies they burn 1,000 hours without a perceptible decrease of candle-power.

The following figures give a comparison between the *energy taken and power radiated* from the surfaces of *osram* and *carbon* filaments:—

The filament of a 25-c.p. osram lamp, consuming per mean horizontal candle-power 1·1 watts, has a total surface of about 50 sq. mm., which equals per candle-power 2 sq. mm., or per watt of supplied energy, 1·8 sq. mm. A good surfaced carbon filament consumes per mean horizontal candle-power 3·5 watts = per candle-power 5·5 sq. mm., or per watt of supplied energy 1·57 sq. mm. It results, therefore, that 1 sq. mm. surface of osram filament gives 0·5 c.p., and consumes 0·55 watt. 1 sq. mm. surface of carbon filament gives 0·182 c.p., and consumes 0·63 watt.

RADIATION.

It will be seen from the above figures that the osram filament radiates only 87 per cent. of the energy radiated by an equal surface of the carbon filament, but gives 275 per cent. of the light given by the carbon filament.

If the kind of radiation were the same in both cases the carbon filament ought to get hotter than the osram filament by about 60° C., because of the higher total radiation per unit of surface. On the other hand, considering the greater light emanating from the osram filament, it ought to exceed the carbon filament by about 200° C.

These contradictory conclusions show clearly how different is the radiating power of the osram filament as compared with the carbon filament. The latter behaves much more like the "black body" of the radiation theory.

From approximate calculations the temperature of an osram filament burning at 1·1 watts per candle-power is about 250° C. higher than that of a carbon filament burning at 3·5 watts per candle-power. If a carbon filament were to be overrun to such an extent as to consume only 1·1 watts per candle-power, its temperature would then have to be raised by 360° C.

The favourable radiating properties of the osram filament, therefore, mean that its temperature is 100° lower than that of a carbon filament of the same efficiency. If it were not so possessed of this radiating property it would have to be burnt at an efficiency of 1·5 to 1·6 watts per candle-power, in order that it might have the same life it actually possesses at 1·1 watts per candle-power.

A further favourable property possessed by all tungsten filaments is their *high positive temperature coefficient of electrical resistance.* If one takes the resistance of carbon, tantalum, osmium, and tungsten filaments at ordinary temperatures, the resistances at those temperatures which, in a vacuum, correspond to 1·5 watts per candle will be as follows:—

For a carbon filament ...	... 0·55 of the original.
For a tantalum filament	... 5·70 times.
For an osmium filament	... 8·50 times.
For a tungsten filament...	... 11·00 times the original.

At temperatures of about 2,200° C. absolute, each increase of temperature of 10° increases the resistance of a tungsten filament about 0·45 per cent.

If the pressure is raised from 100 to 104·5 volts, the current rises from 1 to 1·027 amperes.

For a carbon filament the amount of the increase would be from 1 to 1·05 amperes.

The total energy supplied, therefore, rises in the former case about 7·3 per cent., and in the latter about 9·7 per cent.

Near the normal conditions the light of a carbon filament lamp

rises and falls with the 6·3 power, that of a tungsten filament lamp with the 3·6 power, of the voltage.

The latter differences are too great to be explained by the increase of energy caused by the change of pressure.

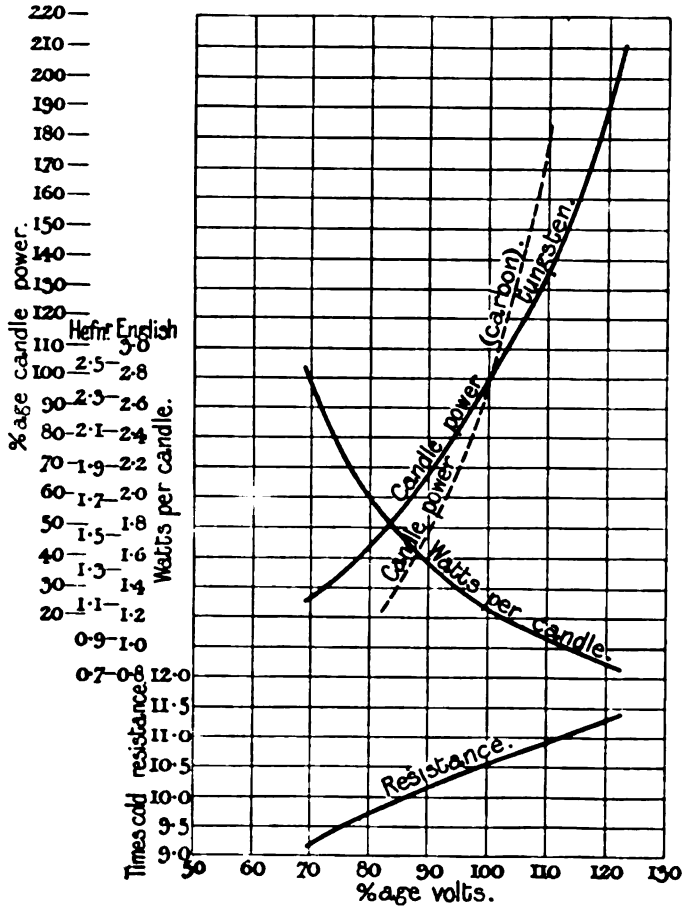


FIG. 1.

The small changes in the *light* of the osram lamp, as compared with a carbon lamp for the same change of voltage, can only be completely explained by the supposition that with a change of energy the radiated light is altered in a different way with the two lamps. A simple calculation shows that near the normal efficiency the light of a carbon lamp changes with the third power of the energy, whilst such change for an osram lamp progresses with 2·3 power of the energy. These

proportions have a very important practical consequence, which is clearly shown by the accompanying curve (Fig. 1) and Table I.

TABLE I.

	Osram.	Carbon.
Increase of light due to 10 per cent. increase in voltage	36 per cent.	84 per cent.
Decrease of light due to 6 per cent. decrease of voltage	21 „	34 „

It will be seen that the osram lamp is much less affected by changes in voltages. Thus, if the pressure is decreased by 6 per cent. from the normal, the light from a carbon filament lamp is reduced so much that it is a considerable drawback, whilst the reduction of light from the osram lamp is not considerable.

HIGH-VOLTAGE LAMPS.

High-voltage metallic filaments of the osram type have recently been put upon the market, manufactured both by the D.G.A. and the Just-Hanaman processes. A number of these have been tested in commercial use and under special conditions to ascertain their life. From the results obtained, the average life of a 1-watt 1-c.p. lamp seems to be between 800 and 1,000 hours. During this period there is no appreciable drop in candle-power, and the lamps have shown themselves to be equally good as the low-voltage osram or Just lamps. These high-voltage lamps, made for from 200 to 250 volts, require double the number of filaments used in the low-voltage lamps. It is evident, therefore, that they cannot be produced for small candle-power. Up to the present 40- to 50-c.p. is about the lowest unit that has been obtained in a commercial lamp, and some extraordinary development or discovery will have to be made before that candle-power can be largely reduced.

THE USE OF 110-VOLT LAMPS ON 220-VOLT CIRCUITS.

In so far as the lamp is different from the carbon lamp, it will, therefore, always be necessary to rely on *series running* whenever low units of light are required on high-voltage circuits; thus, for public lighting (especially for the lighting of large spaces), the convenience of one lamp will be apparent, and people will stretch a point to use 50-c.p. for such purposes whenever they can; but for the use of private houses and confined spaces it will always be necessary to revert to lamps burning in series.

To meet this demand, elaborate arrangements have been made at the Osram Works for testing lamps that will run in series. They are

tested to one-hundredth of an ampere, and sorted out in from five to seven series numbers according to the type of lamp and carefully marked, and the reference numbers (ranging from, say, 28 to 38, which are marked on the caps of all lamps singled out for series burning) practically mean the consumption of current is 0·028, 0·029, 0·030, 0·031, etc., of an ampere.

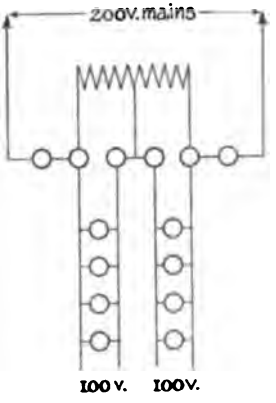


FIG. 2.

This running of osram lamps in series can be avoided to a very large extent in those areas where the supply is given on the alternate-current system. In such cases, where the wiring of the premises to be lighted is carried out on the *sub-circuit principle* (as recommended in the wiring rules of this Institution), it is an easy matter to group up the circuit into two halves, and to connect these halves in series. If it could be insured that there would be always an equal number of lights burning in each of the groups of circuits connected in series in this way, nothing further need be done. As this is not possible in most cases, an auto-transformer has to be added, and connected up as shown in Fig. 2. These tungsten filament lamps burn equally well on either continuous or alternating current, and are quite independent of both frequency and wave-form.

THE EFFECT OF METALLIC FILAMENT LAMPS ON SUPPLY SYSTEMS.

Fears have been expressed by some electrical engineers that the introduction of these osram lamps will seriously affect the finances of supply undertakings. As I pointed out in the introduction of this paper, exactly the same fears were expressed by gas engineers when Welsbach mantles were introduced, which enabled the gas required to produce a given quantity of light to be reduced to one-third of that previously used. These fears proved groundless, and the demand for gas increased instead of decreased. I feel confident that the same result will follow the commercial use of the metallic filament lamp. It seems likely that the introduction of these lamps *will mean an increase of* 100 *per cent. in the unit* adopted for electric light. Sixteen-c.p. carbon lamps will be replaced by 25 to 35 watt tungsten lamps, and those places in which a low illumination is desired will still be supplied with carbon filament lamps of 2½, 5, and perhaps 8 c.p. As it is not practicable at present to make osram lamps for 110-volt circuits of a lower candle-power than 25, it is likely that in small rooms greater illumination will have to be used. Where larger spaces have to be lighted, it is easily possible to obtain the present illumination by using fewer lamps, but I think that, with the cheaper light, the general tendency will be towards higher illumination.

Generally speaking, I do not think that the metallic filament lamp will decrease the current consumption of existing consumers to the extent expected, but will, instead, lead to a large increase in the amount of illumination. At the same time the high efficiency of the lamp, compared with all other forms of lighting, will turn the scale in the favour of the use of electric light rather than other illuminants. Station engineers will find that the increased load from new consumers will more than make up for the decreased consumption of existing ones. This conclusion has already been proved to be correct by Mr. C. P. Sparks, Mr. A. H. Seabrook, and others.

As has been the case with so many new inventions, so the tungsten lamp on its introduction had to run the gauntlet of many reproaches on the part of the more conservative elements in our profession. I think it well to allude as fully as possible to what have been termed the disadvantages of the lamp. Amongst these is the *burning in vertical position*, which up to now has been insisted upon by the manufacturers. This problem is already solved in different ways, and lamps can now be supplied to burn in any position.

The price of these lamps is for the moment a trifle higher, but before many months I believe they will be supplied at the same price as the others.

The *price* itself is naturally held up as a disadvantage, especially when a consumer is displacing old lamps for new ones. The outlay then appears serious, but Table II. shows that the saving in current for given illumination rapidly wipes off this expenditure.

Much has been made of the brittleness of the metallic filament and of the percentage of *breakage* in certain instances. I have no experience of what the makers of tantalum lamps have found in this respect, but from the moment it was understood how to pack the osram lamp the breakage in bulk has been a negligible quantity. It now only affects the supply of the lamps in small parcels of one half-dozen to one dozen. This problem is now being dealt with, with every prospect of an early success.

Another point about which there has been considerable outcry is the *blackening* of individual bulbs which occasionally occurs. It is at present thought that this blackening is due to some extent to the great sensitiveness of the filament to small changes in vacuum. Other theories exist as to the cause of this, but what for the moment mainly interests the users is that if a lamp is going to blacken it usually happens at a very early period of its life, when the makers are prepared to deal with the matter generously. It is quite different in this respect to a carbon lamp, in which a blackened bulb means as a rule that the lamp has been kept on circuit for an indefinite period, far exceeding its useful life.

Having dealt with these points, I would call attention to the other data on Table II. and to the following curves (Figs. 3, 4, 5, and 6), showing some characteristic tests of osram, tungsten, and tantalum lamps made by various independent testing authorities.

TABLE II.

Life Test Results

No. of Test.	Type.	Cost per Lamp.	Tested by	Starting. Watts.	Starting. C.P.	Efficiency in W. C.P.	Number of Lamps.	Duration of Test.	Average Useful Life.	Mean Efficiency.	Average C.P.-hours.	Cost per 1,000 C.P.-hours. Renewals.	Energy at 4d. per Unit.	Total.
	Low Voltage.	d.						Hours.	Hours.	W. C.P.		d.	d.	d.
I.	Osram	48	Faraday House	35·7	36·3	0·99	12	2,000	1,520	1·12	48,700	0·98	4·48	5·46
II.	Osram	48	Westminster Testing Laboratory	35·8	29·7	1·22	12	1,500	1,360	1·29	36,600	1·31	5·16	6·47
IIA.*	Osram	48	Westminster Testing Laboratory	35·8	29·7	1·22	12	3,350	2,850	1·42	70,800	0·67	5·68	6·35
III.	Osram	48	T. R. Charlottenburg	34·7	1·0	1·12	(?)	1,000	1,000	1·11	31,100	1·54	4·44	5·98
IV.	Osram	48	Robertson E. L., Ltd.	35·0	27·7	1·26	6	1,800	1,720	1·36	45,600	1·06	5·44	6·50
V.	Wolfram	48	Robertson E. L., Ltd.	38·0	30·7	1·24	2	1,000	1,000	1·27	28,900	1·66	5·08	6·74
VI.	Tantalum	33	Westminster T. L.	39·1	22·0	1·78	6	1,000	700	1·84	15,000	2·19	7·36	9·55
VII.	Carbon	12	—	59·0	18·7	3·15	10	1,000	1,000	3·25	18,000	0·67	13·00	13·67
	High Voltage.													
VIII.	Wolfram	90	Robertson E. L., Ltd.	63·4	53·7	1·18	10	880	720	1·12	42,500	2·12	4·48	6·60
IX.	Carbon	12	—	68·0	18·9	3·6	10	1,000	1,000	3·95	18,200	0·66	15·80	16·46

NOTE.—For the purpose of comparison *all* the above results have been expressed in terms of the "Hefner" unit of candle-power.

* This is a continuation of Test II. to 3,350 hours to show that it pays to burn osram lamps to the limit of life.

The samples of osram lamps were selected at efficiencies corresponding to the limits of sorting, that is, 1·0 to 1·25 watts per candle-power, so that they represent the lowest and highest efficiency at present on the market.

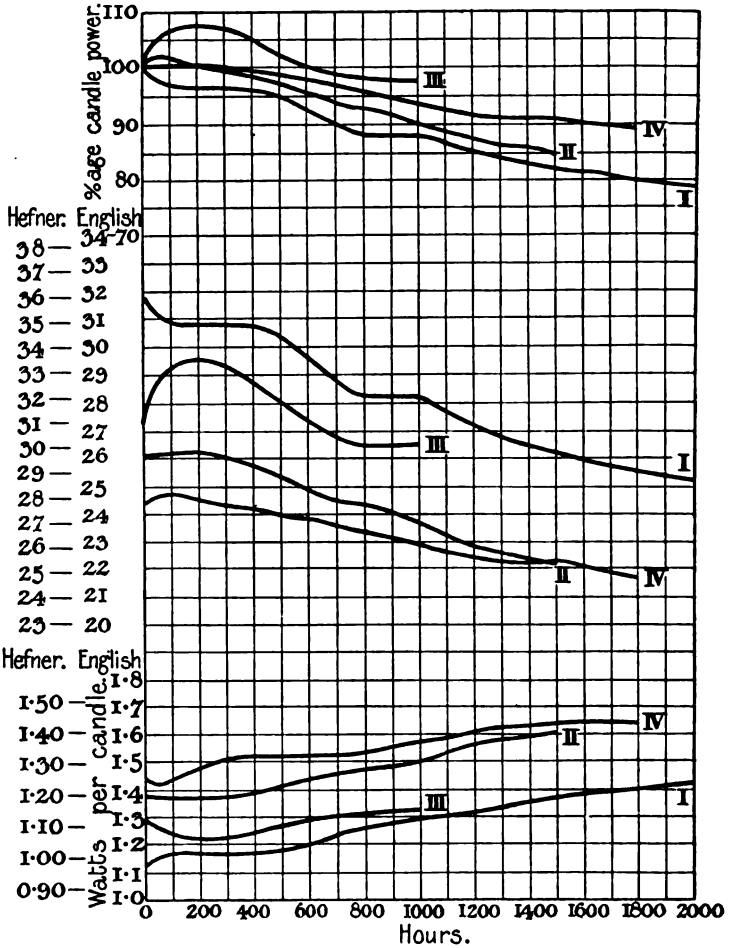


FIG. 3.—"Osram" Average Life Test Curves, etc.

Test I. on Table II. and Fig. 3 is a good example of an osram lamp. This was made by Faraday House on an ordinary commercial lighting circuit, alternating current, with a variation of voltage of about 3 per cent. each way. Twelve lamps were tested, and nine gave a life of 2,000 hours, with a 20 per cent. drop in candle-power. The first failure

took place at 900 hours, the other two failures following between 1,200 and 1,400 hours. The cost of lighting with such lamps comes out at the very low figure, including renewals, of 5¾d. per 1,000 c.p.-hours.

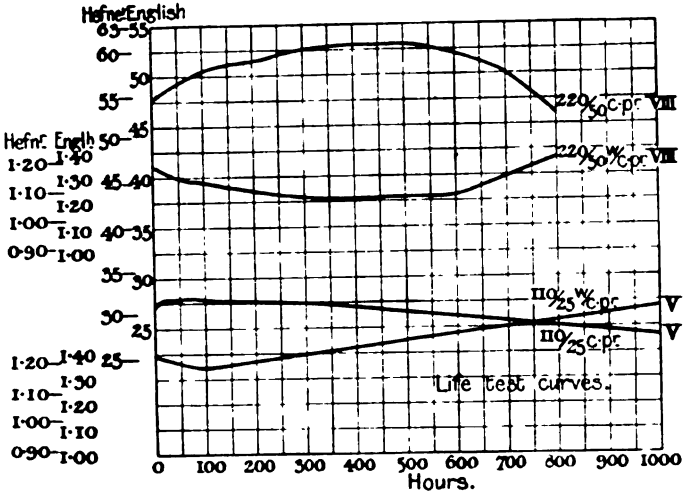


FIG. 4.—"Just-Wolfram."

Tests II. and IIA. on Fig. 3 are other examples of osram lamps burnt at a slightly lower efficiency, and after 1,500 hours' use the drop

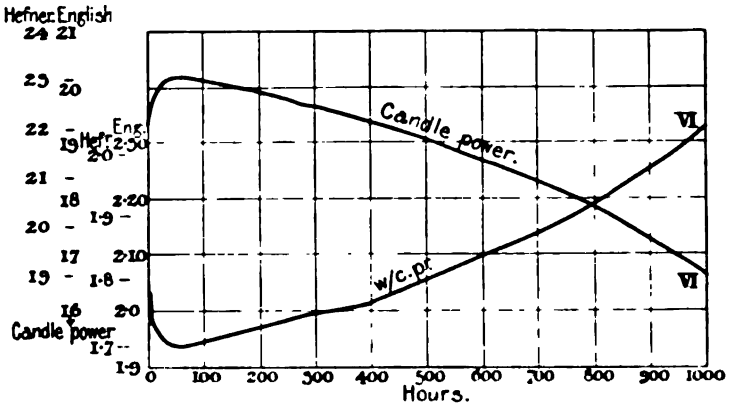


FIG. 5.—Tantalum Lamps.

in candle-power only amounted to 11 per cent. This test was continued to 3,350 hours, when nine lamps were still good. Their average candle-power was then 70 per cent. of the initial candle-power. It

is interesting to note from this test that it pays to run these lamps to a point when the candle-power has dropped 30 per cent., as will be seen from the table.

The test No. V. on Fig. 4 of tungsten lamps made by the Just-Hanaman process shows that these lamps are quite as good as the osram.

The test was only carried to 1,000 hours, but it is quite possible that the lamp could have lasted up to 2,000 hours or more, with a proportionate reduction in the cost of renewals. After the 1,000 hours the

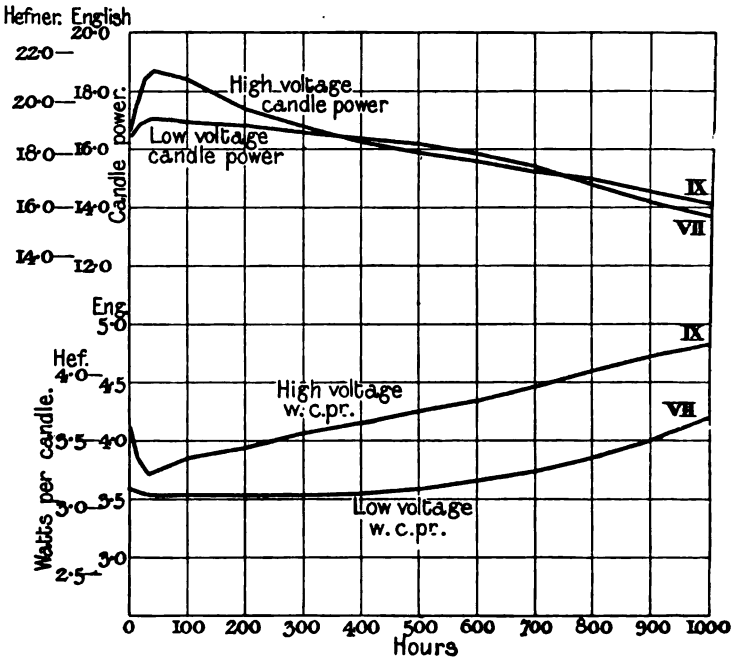


FIG. 6.—Carbon Lamps.

drop in candle-power was exceedingly small, amounting to only 3 per cent.

The tantalum tests, No. VI. on Fig. 5, give a much less favourable result than the above figures.

The test is a typical performance on a direct-current circuit. The cost per thousand candle-hours works out at 9½d., or 73 per cent. more than the osram lamp.

The carbon filament lamp results, test No. VII. on Fig. 6, were selected from a large number of tests, and represent the average English-made lamp.

A comparison of the figures in the last column of Table II. shows that the total saving from the use of osram lamps over carbon lamps when equal voltages are compared is 60 per cent.

Test No. VIII. in Table II. shows the high-voltage trials of tungsten lamps, which were made on an ordinary alternating-current lighting circuit, 50 cycles, with a voltage variation of 5 per cent., most of the variation being up. The figures show that, even paying 7s. 6d. for these 65-watt lamps, there is a saving of over 60 per cent. over the average high-voltage carbon lamp (test No. IX. on Fig. 6) when all the factors of the cost are considered.

In all of the above examples the price of current has been taken as 4d. per unit, which is a fair average for lighting at the present time. Of course with higher prices per unit the saving from the use of tungsten metallic filament lamps is still greater.

As an instance of the life of osram lamps for public lighting, I append figures showing the life of the lamps installed in the streets of Canterbury, which have been kindly furnished by the Borough Engineer, Mr. C. A. Blascheck.

CANTERBURY.

LIFE OF OSRAM LAMPS ERECTED IN THE STREETS, MARCH, 1908.

OSRAM LAMPS.

St. George's Place.		(*Lamps in Open.*)
Post No. 37...	1,357	hours burning.
	*2,434	,, ,,
Post No. 38...	1,971	,, ,,
	2,036	,, ,,
	93	,, ,,
Post No. 39...	*2,434	,, ,,
	*2,434	,, ,,
Post No. 40...	1,779	,, ,,
	*2,434	,, ,,
Post No. 41...	*2,434	,, ,,
	*2,434	,, ,,
Post No. 42...	1,665	,, ,,
	*2,434	,, ,,
Post No. 63...	974	,, ,,
	2	,, ,,
	*2,434	,, ,,
16 lamps	29,349	total hours burning.

Average hours = 1,834.

NOTE.—Those marked * are still burning, therefore the actual average life on completion of test will be considerably higher.

Dover Street and Oaten Hill. (*Lanterns enclosing the Lamps.*)

Post No. 179		1,402	hours burning.
		1,500	„ „
Post No. 180		484	„ „
		*2,464	„ „
Post No. 181		829	„ „
		*2,464	„ „
Post No. 182		*2,464	„ „
		*2,464	„ „
Post No. 183		*2,464	„ „
		*2,464	„ „
Post No. 184		*2,464	„ „
		*2,464	„ „
Post No. 185		*2,464	„ „
		*2,464	„ „
Post No. 205		*2,464	„ „
		*2,464	„ „
Post No. 206		2,315	„ „
		*2,464	„ „
Post No. 207		712	„ „
		800	„ „
		639	„ „
		1,068	„ „
Post No. 208		430	„ „
		736	„ „
		736	„ „
		1,960	„ „
		1,403	„ „
Post No. 255		*2,464	„ „
		*2,464	„ „
29 lamps		51,974	total hours burning.

Average hours = 1,792.

NOTE.—Those marked * are still burning, therefore the actual average life on completion of test will be considerably higher.

SPECIAL APPLICATIONS.

25-volt Osram Lamps.—What I have said as to the likelihood that the metallic filament lamps will raise the standard of illumination, owing to the impossibility of making small candle-power lamps, applies only to those cases in which the lamps are connected on to standard supply systems at 110 volts, or two in series across 220-volt circuits.

The advantages of the pure tungsten filaments can be obtained with small candle-power lamps when a lower voltage of supply is adopted.

As an example of this, osram lamps for 25-volt circuits have been standardised for both 10 and 16 c.p. These lamps consume respectively 10 and 16 watts, and for this consumption give the same candle-power as the ordinary carbon filament lamps taking 40 and 60 watts. It is somewhat difficult to make use of these low-voltage lamps when only continuous current is available from the public mains. Then, in order to reduce the voltage, motor-generators, double commutator balancers, or rotary converters have to be used.

While these are quite serviceable commercially when large numbers of lamps have to be supplied, the low efficiency of small sets, and the attention which the additional rotating machinery involves, will limit the extensive application in this direction.

When alternating currents are distributed the case is entirely different, as static transformers can be used which require no attention and have high efficiency. The low voltage required for these small candle-power lamps can then be obtained at a cost which brings them into effective competition with the incandescent gas mantle for private house lighting.

The opinion has often been expressed, and is still held by many, that the cost of the transformer, together with the losses in the same, would more than nullify the saving from the use of metallic filament lamps. The iron loss in such transformers is constant, and goes on whether the lights are burning or not. Hence, to get the best result, these transformers, like those still largely used for reducing high pressure to, say, 220 volts for house lighting, must be designed with a minimum of iron loss so as to obtain a high all-day efficiency.

For use with these lamps special transformers have been constructed on the above lines, from which the following figures have been obtained on test :—

The iron loss on the transformer designed for 300 watts output is as low as 5 watts.

The following table shows the units taken per year by this and two other transformers of a larger size to overcome iron losses :—

TABLE III.

Details of Iron Losses of Small Transformers.

Output of Transformer in Watts	Number of 16-c.p. Osram Lamps Alight at one Time.	No Load.	Iron Losses	Units Taken per Year.	Cost per Year at 4d. per Unit.
		Watts.	Percentage		£ s. d.
300	19	5	1·67	44	0 14 8
750	47	10	1·33	88	1 9 4
1,500	94	17	1·13	149	2 9 8

The cost per year at 4d. per unit is given in the last column.

The copper losses in these transformers are not large, and only occur when the lamps are being used. The total loss in the copper of the transformer, and in the wires between the transformer and the lamps, will not be appreciably higher than the copper losses in the cables alone when carbon lamps are used.

The following table shows the financial results from the use of these 25-volt 16-c.p. osram lamps in a private house requiring 25 lamps. I have assumed that the smallest size of transformer in the preceding table will suffice, as 19 lamps alight at one time is about the extreme maximum load in such a house. The total saving in current shown in the last column varies with the number of hours the lamps are in use; at 500 hours' use the saving in current is £6 4s. 9d. on a yearly bill of £9 10s. when carbon lamps are used. The current account is thus reduced 65 per cent., but the bill for lamp renewals will be somewhat higher.

TABLE IV.

Annual Costs for Current on an Installation of 25 16-c.p. Lamps, of which 19 are Burning at one Time.

(16-watt Osram Lamp *v.* 60-watt Carbon Lamp.)

No. of Hours per Annum at Maximum Load.	Maximum Load in Watts.		Units used per Annum with Osram Lamps.			Units used for Carbon Lamps.	Cost of Current at 4d. per Unit.		
	Osram Lamps.	Carbon Lamps.	Osram Lamps.	Transformer.	Total.		Osram Lamps.	Carbon Lamps.	Saving.
							£ s. d.	£ s. d.	£ s. d.
300	304	1,140	91	44	135	342	2 5 0	5 14 0	3 9 0
400	304	1,140	122	44	166	456	2 15 3	7 12 0	4 16 9
500	304	1,140	152	44	196	570	3 5 3	9 10 0	6 4 9
600	304	1,140	182	44	226	684	3 15 3	11 8 0	7 12 9
700	304	1,140	213	44	257	798	4 6 6	13 8 0	9 1 6
800	304	1,140	243	44	287	812	4 15 6	15 4 0	10 8 6

Table V. shows the complete balance sheet obtained by adding the cost of current to the lamp renewal charges for both carbon and osram lamps.

These tables clearly show that private houses in those areas over which electricity is distributed in the form of alternating current can at once realise to the full the exceptional radiating properties of the tungsten filament.

As some engineers may object to my statement above as to the

TABLE V.

No. of Hours per Annum of Maximum Load.	Osram Lamps.		Carbon Lamps.		Total.		Total Saving with Osram.	
	Current.	Lamp Renewals.	Current.	Lamp Renewals.	Osram Lamps.	Carbon Lamps.		
	£ s. d.	£ s. d.	£ s. d.	s. d.	£ s. d.	£ s. d.	£ s. d.	%
300	2 5 0	1 10 0	5 14 0	7 1	3 15 0	6 1 1	2 6 1	38
400	2 15 3	2 0 0	7 12 0	9 6	4 15 3	8 1 6	3 6 3	41
500	3 5 3	2 10 0	9 10 0	11 10	5 15 3	10 1 10	4 6 7	43
600	3 15 3	3 0 0	11 8 0	13 3	6 15 3	12 1 3	5 6 0	44
700	4 5 6	3 10 0	13 6 0	16 7	7 15 6	12 2 7	6 7 1	45
800	4 15 6	4 0 0	15 4 0	19 0	8 15 6	16 3 0	7 7 6	45½

copper losses of the transformer being small, I give below a formula which will enable them to calculate what the comparative cost of osram and carbon lamps would be if these copper losses are also taken into account.

Using the following symbols :—

a = open circuit loss in watts.
b = number of lamps.
c = candle-power.
d = cost per unit.
e = average hours of running per year.
f = copper loss on average load.

The cost of lighting with osram lamps per year works out at—

$$8{\cdot}76\,a\,d + \frac{b\,c\,e\,d}{1{,}000} + \frac{f\,e\,d}{1{,}000}.$$

The yearly cost of lighting with carbon filament lamps as against this, works out to be—

$$3{\cdot}5\,\frac{b\,c\,e\,d}{1{,}000}.$$

This under the assumption of an efficiency of 1 watt per Hefner candle for the osram lamp and 3·5 watts for the carbon filament lamp.

The saving in running cost, therefore, is per year—

$$3{\cdot}5\,\frac{b\,c\,e\,d}{1{,}000} - 8{\cdot}76\,a\,d - \frac{b\,c\,e\,d}{1{,}000} - \frac{f\,e\,d}{1{,}000}$$

$$= d\left(\frac{2{\cdot}5\,b\,c\,e - f\,e}{1{,}000} - 8{\cdot}76\,a\right).$$

If we take the cost of an actual installation as an example, and figure on 25 16-c.p. lamps (*b* equal to 25, *c* equal to 16) and take from actual measure—

a	= 5
f (to be on the safe side the maximum copper loss has been taken, not the average) ...	= 12
d	= 4d.
e	= 1,000.

Under these conditions the saving works out, as per above formula, to £15 14s. 9d. on a total of £23 6s. 8d., equivalent to a *saving of* 67·4 *per cent.*

If we had not transformed down, but taken the smallest obtainable candle-power, namely 28-watt osrams (against 16-c.p. carbon lamps), the saving would have been £11 13s. 4d., equal to 50 per cent.

If we take further into consideration the cost of renewals and the additional cost of the transformer, we find :—

	£	s.	d.
First cost of transformer	2	2	0
Amounting to an annual outlay (reckoning on five years' amortisation) about ...	0	9	0
Cost of renewals for osram lamps 25 × 3s.	3	15	0
Cost of renewals for carbon lamps 25 × 1s. 3d.	1	11	3
Difference	2	3	9

The actual saving is therefore £15 14s. 9d. minus £2 12s. 9d. = £13 2s., which is equivalent to 56·2 per cent.

The no-load losses have decreased the original saving in running cost by 4·5 per cent.; the copper losses by 1 per cent. (therefore from 67·4 per cent. to 62 per cent.).

An unexpected objection has arisen to the use of these small transformers from certain central station engineers—they find that the iron losses are so small that they will not keep the meter running. If this is the case, these iron losses, which should be borne by the consumer, fall on the station—which is obviously incorrect.

There is no reason why this should not be done if the station engineer is allowed to charge for the same.

With the high-pressure distribution, using transformers in consumers' houses, which was common practice ten years ago, the electricity meters were always placed on the low-tension side of the transformer, and the price per unit was fixed with due consideration of this fact. I would suggest, therefore, that those supply engineers who wish to make use of osram lamps to extend their private-house load should themselves supply these small transformers and charge the consumers a slight increase per unit to cover the iron losses, and also the capital expenditure involved.

There is another large field for these low voltage lamps in connection with isolated plants for the supply of country houses, workshops, etc. Where small units of light are quite sufficient, the cost of the generating plant can be reduced very largely as the output required falls in the ratio of the efficiency of the filaments used in the lamps. Thus the maximum load in any given case falls in the ratio of $3\frac{1}{4}$ to 1, and neither the factory inspector from the Home Office nor the fire insurance company claims that supply at 25 volts is dangerous.

The same reduction in the cost of generating plant in mains can be realised when designing electric lighting equipment for the numerous small towns and villages within the United Kingdom yet to be supplied with electrical energy. In such undertakings the capital burden to be borne by the relatively few consumers obtainable is the chief deterrent.

While the saving from the use of the metallic filament lamp may not bring the capital down quite in the above ratio, it will make many schemes feasible which hitherto have been passed by.

Discussion.

Mr. Haydn T. Harrison: I think we are to be congratulated that Mr. Hirst has been able to read this paper, since he has a more intimate knowledge of the possibilities of the tungsten filament lamp probably than anybody else in this country. On page 645 he compares, as everybody probably will have done, the tungsten lamp with the gas mantle, but there is one point which he does not call attention to, and that is that the gas mantle differs in a most important feature; that is, in the first 100 hours of burning the candle-power of the average gas mantle drops 20 per cent., and in 500 hours from 40 to 50 per cent.; whereas the tungsten lamp has this peculiarity, that in 1,000 hours it drops less than 10 per cent. So that the tungsten lamp is nearly equal in efficiency as far as cost per candle is concerned, and it is more than equal in efficiency as regards steadiness in illumination. On page 648 Mr. Hirst says that it will require some extraordinary developments or discovery to produce a tungsten filament lamp of lower candle-power for higher voltages. In his remarks just now he referred to a patent of the General Electric Company of America, a mercury process, but I believe that in that very same application they also mention another point—namely, that tungsten when increased in temperature, even below that of oxidisation in the atmosphere, becomes ductile, and therefore they refer to a process of drawing it down. I want to ask the author whether he thinks that this is practical or not. These filaments, as has been explained, are not drawn filaments, but if tungsten is ductile at a temperature below oxidation, of course there may be considerable possibilities in that particular idea. The author states that elaborate arrangements are being made for testing the lamps to $\frac{1}{100}$ of an ampere, but as the lamps only take $\frac{1}{10}$ of an ampere that is rather a Mr. Harrison.

Mr. Harrison.

large percentage; it is 3 to 4 per cent. of the current that the lamps are taking. Thus a lamp taking 0·3 of an ampere might vary 6 per cent. in current from another lamp marked the same, and, what is more, it might vary nearly 8 to 10 per cent. in volts, because the temperature coefficient of tungsten itself varies with the volts in greater proportion than the current varies. Therefore I think there must be some error somewhere, because nearly every ammeter or instrument used in a lamp factory will work within closer limits than this. In practice I have found that big units of light are appreciated for this reason, that if one has an economical large unit of light one can afford to diffuse it. I suppose one of the greatest disadvantages in electric incandescent lighting has been the high intrinsic brilliancy of the filaments themselves. I personally have never used osram lamps in a house unless they have been either frosted or put into globes where the filament is not visible. We could not afford that with a carbon filament lamp, but with one watt a candle one can afford to put the lamps into such a position that the eye does not suffer from that high brilliancy, and it is one of the greatest advantages from the physiological point of view that I have met with. Mr. Hirst all the way through his paper makes a comparison of osram lamps with other incandescent electric lamps and gas lamps. I do not know whether many people have realised the fact that the lamp which is giving light at one watt a candle takes it into a much bigger region than that. The enclosed arc lamp, for instance, takes more than one watt a candle; in fact, the smaller lamps are nearer two watts a candle. Open type arc lamps for street lighting purposes—that is to say, where very nearly horizontal rays are mostly used—are taking over one watt a candle. Therefore it comes to a question of watts absorbed and cost of renewals or cost of labour and carbons. I have worked it out that where big units are required up to, say, 500 or 600 c.p. the open-type arc which gives 500 c.p. at 10° below the horizontal and takes 500 to 550 watts is less economical than a group of osram lamps giving 500 c.p., because the cost of carbons and labour is considerably higher than the cost of lamp renewals. It is rather a curious coincidence that this paper refers to Canterbury figures. I happened to see Mr. Blascheck last week, and he told me that a large number of the lamps mentioned as lasting 2,400 hours are still burning, and that has brought the average life of the lamps referred to as burning in the streets of Canterbury, to over 2,000 hours.

Mr. Drake.

Mr. B. M. DRAKE: As might have been expected, Mr. Hirst's paper is essentially of a practical nature. I had the honour of being associated with him in connection with the Nernst electric light, and a very difficult problem we found it. It must be a relief to him, after the troubles we encountered, to find himself sailing in smoother waters. The advent of the metallic filament lamp at this period of the electrical industry is most welcome, at any rate to those who are connected with private plants, for up to the present the electric light has been so costly that, although admittedly the best light, many people have been

forced to adopt some inferior illuminant on the score of expense. From the central station point of view I can well understand that it is not so acceptable; for many small stations have already secured the only people who are likely to adopt electric light, and if the income from these is halved the Company may well find it difficult to pay a dividend. I thoroughly agree with the previous speaker, that the best chance for the engineers in charge is to use their endeavours to get people to use their light in a more rational way. The ordinary pendant light with a clear filament, which may damage sensitive eyes, could very well be replaced with a lamp of two or three times the candle-power if the shade were arranged on the under-side instead of above the lamp. This would materially improve the diffusion of the light, appease the oculists, and keep the supply company's accounts at their present level. As regards the name, I think Mr. Mordey suggested that "metallic filament lamp" was too lengthy for this life, and he suggested "wire lamp," but this applies more to the tantalum than to the squirted tungsten filament, and I venture to suggest as an alternative "metal lamp." A difficulty with tungsten lamps has been to get them to the customers without breakage of the filament. Mr. Hirst's Company has solved this in a practical way when sent in bulk; in fact, lamps sent in their casks arrive with only 2 per cent breakages, but in small quantities it is still a problem. With the tantalum lamp, which is much stronger, no special precautions are necessary, and therefore up to recently the tantalum has perhaps been most favoured. In dealing with metal lamps in large quantities certain phenomena have come to my notice which perhaps some one may be able to explain. It has been stated by several users that the metal lamps have a longer life in winter than in summer. Can this be due to temperature, or to the number of times they are switched on and off? Also they are stated to blacken more if enclosed in an outer shade. Others have said that where the lamps are used in streets and exposed to the sun's rays the life is shortened. Tantalum lamps, as probably most people know, have a longer life on alternating current with low than high frequency. This seems to point to the fact that the breakages are due to molecular vibration, which is borne out by the fact that when they do fail they generally break in several places. For some time there was an opinion that the polarity of the tantalum lamp ought not to be reversed, and in some of the earlier tests this seemed to be borne out, but recently I have not heard that it makes any difference. We have had to compete recently in private installations with two forms of light, acetylene and petrol gas. The acetylene has been preferred by many on account of its colour, for it is stated to be the colour nearest to sunlight, but the cost of working is high. For 1,000-c.p. hours, which the author has taken in his paper as a standard, as far as I have been able to ascertain the working cost of acetylene comes out at 2·2d. per 1,000-c.p. hour. Taking one watt per candle power, the electric light with low-voltage installations comes out at 2d. Petrol gas seems to vary from 1·3d. upwards according to the price of petrol in the district

Mr. Drake.

Mr. Drake. and the veracity of the salesman. At any rate, it is safe to say that the metal lamp has again put us in the running, and although from a central station point of view it may be looked upon as a temporary drawback, I am quite sure it will benefit the industry in the end.

Dr. Bell. Dr. LOUIS BELL: I can perhaps add nothing which would be of more interest to the members present than to say something on the development of metallic filament lamp working in America as we find it to-day. We have many metallic filament lamps in use. At first came the tantalum lamp, which was received with open arms, with a great deal of enthusiasm, but that was very promptly pushed aside by the tungsten lamp as soon as the latter came in. The reason for this was that a very large number of our distributing circuits are alternating-current circuits, and the tantalum lamp, as we all know, is comparatively ineffective on those circuits by reason of its shortened life. The life, from my own experience, is about two-thirds of that which is obtained on direct current. The shortening of the life comes through faulting of the filament. Sometimes it faults altogether, and sometimes incipient breaks show almost every quarter millimetre through the entire length of it. In addition to what Mr. Drake has said, I may add that the tantalum filament works badly both at high frequencies and very low frequencies. I have experimented considerably on the cause of the failure in life on alternating current, and the facts seem to be these, that the faulting in the filament is due to the continued heating and cooling rather than to anything else, that heating and cooling take place more rapidly and go through a larger number of cycles as the frequency rises. On the other hand, the temperature change through the thermal inertia of the filament becomes at a higher frequency somewhat less; the cooling off effect is less complete. As a result, after having carried out a large number of experiments at all sorts of frequencies, I find that at 60 ∿ and above, particularly above 60 ∿, the life was very materially limited, while on the other hand, at a very low frequency, 5 or 10 ∿, the lamps could be hardly put in fast enough to keep them alight. The heating and cooling were so complete at those low cycles that the faulting became very marked, and instead of being partial was complete; the lamp went as soon as faulting was initiated. Then came the tungsten lamp, at first in the form of a few of the imported lamps, made in part by the Just-Hanaman process and in part by the colloid process. It was later taken up by the General Electric Company, which now produces most of the lamps we have in use. The lamp which was first put out was a 100-watt 80-c.p. lamp. We are working over there at 1¼ watts per English candle. I think the watt per candle ratings are mostly based on Hefner. The large lamps were most welcome, because they enabled us for the first time to have a successful substitute for the extremely uneconomical enclosed arc which we had been in the habit of using. Enclosed arcs at 80 volts, working on 120-volt circuits, are about as bad an example of lighting as could well be found, and the high-candle-power tungsten lamps

were most welcome in that particular. The manufacturers have been very slow to put out the lower candle-power lamps, but the importation of German lamps has forced them to it, and the standard lamps now out are the 100-watt, 60-watt, and 40-watt sizes. They are substantially like the osram lamps in their general character; the life is excellent, and save for their fragility in shipment the success of the lamp is, on the whole, thoroughly good. I noticed one thing in making a great many life tests on them, namely, that the specific emissivity seems to change through the life of the lamp; so that it is quite common in testing a batch of lamps to find individual lamps, and sometimes nearly all the group, rising in candle-power after they have fallen 10 or 12 per cent., and eventually, after a very long life, breaking. One of the questions uppermost in our minds now is, What is the most economical efficiency at which to run the lamps? At a watt per English candle most of the experiments I have seen indicate that the lamp is being overrun; at 1½-watts per candle the life is most admirable; and in the small candle-power lamps, lamps of 40 watts and below (for we have a few 25-watt lamps even now in use)—at these lower candle-powers, even it is a question in my mind whether it will not pay to work the lamps, considering their high cost, at perhaps 1½ watts per candle-power, where the light is still admirable in quality and the life is very much increased. It will perhaps make a material saving to work the small lamps at a somewhat reduced efficiency. At all events, it might be worth trying, and it is an open question what the final efficiency may be. I may add that casually I have heard several rumours, which I shall try and investigate on the Continent in the next few weeks, that our German friends, who have passed along so many good things in the way of lighting to us, have up their sleeves, carefully concealed for the present, but about to appear, a lamp which will run to ½ watt per Hefner, or something of that sort. If they have that lamp, it is almost certainly not exactly like our present tungsten lamp. It may be only a rumour. In closing I should like to add one thing with regard to the use of these new lamps; and that is to throw out a suggestion that they should always be used, either in such a position that they are fairly without the field of vision, so that the eye will be shielded from them, or else that they should be used behind a diffusing shade. In our American practice tungsten lamps are almost never used except in one of those two positions. The Edison Illuminating Company of Boston has put out a great many of these lamps, and every lamp that comes to the Company comes half frosted; and, moreover, we put on the lamp a shade which has a deep skirt coming down nearly to the tip of the lamp; and in every case where the lamp is to be installed fairly within the field of vision, that shade is sandblasted or etched so that the light is completely diffused so far as the observer's eye is concerned. We make that an invariable rule in putting out the lamps, and I think it is one that should be always followed. The intrinsic brilliancy runs between one and two thousand per square inch, and the effect on the eye is terrific. These new illuminants must be treated in that cautious

Dr. Bell.

Dr. Bell.

way, or otherwise our eyesight will suffer. We have one thing to our advantage there which is not the custom here, and that is that, as a rule, the American central stations furnish free renewals. In that way we are able to control the output of these lamps. They are put out to the customer, not free as a rule, but at a small renewal charge, a renewal charge rather less than the cost of the lamp to the station, but enough to make the consumer and the station share the benefit of the smaller consumption of energy, and I think no American central station engineer has the slightest fear of the economical result. One witty friend of mine referred to the troubles which are existing to-day as merely the growing-pains of the industry, and I think that is a fair characterisation; in fact, one old central station manager, who has been at the forefront in introducing every new thing in electric light for the last fifteen years, told me blandly the other day that he proposed to put out these tungsten lamps free, and added, what I knew to be the fact already, that every time he had reduced his price to the consumer he had increased his net profit. I think if the change is met in that spirit, this new lamp is going to be a boon to the industry all over the world.

Mr. Handcock.

Mr. H. W. HANDCOCK: I certainly hope that some means may be found of settling the standard by which we are to measure our lamps in future. We do not mind whether it is the Hefner or whether it is the standard candle, but let it be one of them. At the present moment a great deal of confusion arises, due to the fact that after making, perhaps, lengthy calculations or carrying on an argument for some time you find that one side has been arguing on the Hefner and the other on the British candle-power. Then comes another point, the present method of measuring the candle-power of lamps. If we take the horizontal standard, I am not sure that it is quite fair to the carbon filament. In the case of the metallic filament, practically the whole of the illumination is horizontal. It is true that has advantages for street lighting, but it is a disadvantage for lighting rooms in certain cases. If we take the horizontal measurement for a metallic filament, and compare it with the horizontal measurement for a carbon filament, disregarding the mean spherical candle-power, and run out the results obtained in watts per candle-power, the result is somewhat to reduce the watts per candle-power for the metallic filament as compared with the watts per candle-power for the carbon filament. I think it will also be found that any object immediately under a 30-watt carbon filament used horizontally is illuminated more effectively than by a 50-watt metallic filament which is preferably used in a vertical position. I do not mean to say that is a fair comparison; it merely illustrates the difficulties that arise through taking all one's measurements in the horizontal plane.

I think we might with advantage lay some stress on the benefits that accrue to central stations from increased facility in regulation. There is no doubt about it that in a building, part of which is lighted with metallic filaments and the other with carbon filaments in the portion

lighted with metallic filaments any variations in regulation are scarcely noticeable, whereas on going into the portion of the building lighted with carbon filaments one's remarks as to the regulation of the station may not be entirely complimentary. Then also I do not think we can lay too much stress on the fact that the candle-power of the metallic filament is so well sustained as compared with that of the carbon filament. It is not a very great advantage to know what is the efficiency of a lamp at the beginning of its life; we want to know the average efficiency for the whole of its life, and from that point of view there is no doubt that the metallic filament is incontestibly superior to the carbon filament. It is a matter of wonder when one comes to consider what a remarkably good lamp has been produced in so short a time in the form of the metallic filament lamp, having regard to the many years that were necessary to bring the carbon filament to its present state of perfection. Mr. Handcock.

There are one or two practical drawbacks in the use of lamps which perhaps one need scarcely refer to. If we are to use metallic filaments on 200 volts, we want something a little in advance of the present arrangement for portable lamps. The portable lamp is an important factor in the ordinary dwelling-house, and for that purpose we must either use the 25-volt lamp or else we must retain the carbon filament. The question as to the effect of metallic filaments on central stations has been threshed out at some length recently. Doubtless there are many gentlemen present who know the results of their own stations, for, say, the last six months' working. Perhaps it is asking too much in the event of its being unfavourable to request them to tell us; but if any gentlemen are present who happen to be able to tell us that there has been an augmentation in the rate of increase of their load, I beg of them to let us know, and set our minds at rest for ever on the point.

I believe the author remarked that recently he had made an offer to London supply stations to supply lamps through them. As I understood it, they were to distribute the lamps, and have the control of them. My own opinion is that the author, from a business point of view, was absolutely right, and that the central stations, when they declined, missed a golden opportunity.

Mr. A. A. CAMPBELL SWINTON: After the very practical remarks that have been made, I am afraid that what I shall say will, perhaps, be considered of rather dry scientific interest only. Without calling in question the statement by the author that it has been shown "that bodies exist which at the same temperature radiate as light a larger percentage of the supplied energy than the so-called 'black-bodies,'" I wish to give my opinion that, at any rate, it is not at the present moment proved that the Welsbach gas mantle owes its high efficiency to this property, as the author states. Dr. Bunte made experiments on this subject. He heated up mantles made of the Welsbach mixture, which is 1 per cent. of ceria and 99 per cent. of thoria, in a furnace. He heated up at the same time in the same furnace to exactly the same Mr. Swinton.

Mr. Swinton. temperature mantles made of pure thoria, and found that they all gave about the same amount of light. In this connection I may refer to a paper I read in 1899 at the Royal Society where similar experiments were described, the two mantles being simultaneously heated by means of cathode rays in a vacuum, when the same result was obtained. With the incandescent mantle, when heated in a Bunsen gas burner, it is well known that the 1 per cent. of ceria enormously increases the amount of light, whereas, as mentioned in the two sets of experiments I have referred to, the addition of the ceria made no appreciable difference at all. This goes to show, I think, that it is not a mere question of selective emissivity, but of catalytic or other action which takes place only when these bodies are heated up by a flame. I only wish to mention this point because I think it is undesirable that a question which is still one of considerable controversy should be referred to as a settled matter.

Mr. Paterson. Mr. C. C. PATERSON: Referring to the author's statement that it is next to impossible to try to standardise metallic filament lamps by candle-power, I do not see why this should not be done, at least from the consumer's point of view, whatever may be the view of the makers. Carbon filament lamps have been standardised by candle-power, and surely if a lamp can be standardised which varies in candle-power as the sixth power of the voltage, we ought to be able to standardise a lamp which varies only as the cube or fourth power. We buy lamps to give candle-power and not to consume watts, whatever the central station man may say. I am sorry to see Mr. Hirst expressing so many results in Hefner candles. We have a British candle, which is a perfectly substantiated one and is used in America and France, and why should we hark back to the Hefner, which is used in Germany and is not generally understood here? At the same time, in the curves, I am pleased to see Mr. Hirst has put in English units as well. I have been looking at a number of test sheets to-day, and noticed the same difference between the initial performance of osram lamps as is shown in Mr. Hirst's diagrams. Some seem to rise largely in the initial stage, as Test No. 3 at the Reichsanstalt; others drop almost at the beginning without any rise. I should like to know if Mr. Hirst can give a reason for this. It would be very interesting to get some idea as to the total output of lamps in Great Britain—how many millions are made during the year and consumed, and how many Mr. Hirst thinks it is possible to replace with metallic filament lamps within the next four or five years. I do not know whether this is too difficult a question to ask, but we should like to get some idea as to what will be the probable output of carbon filament lamps in the near future. Mr. Harrison has made one remark as regards gas mantle tests, namely, that the gas mantle fell off very much from the beginning; I must say that this has not been my experience. I find, when testing in the ordinary way without any special laboratory conditions, that they rise very largely during the first 100 hours or so, but after 150 hours they begin to drop. Referring to Mr. Handcock's point, with regard to the distribution of

light, that the candle-power is always measured in the horizontal position, I really do not think this puts carbon lamps at such a disadvantage. Of course there is some disadvantage, but not more than 5 to 6 per cent. difference. The reduction factor for metallic filament lamps is about 0·8—that is, a reduction from the mean horizontal to the mean spherical. For carbon lamps it is about 0·85. Mr. Paterson.

Mr. T. W. LOWDEN: From the title of this paper one would have expected to learn something about recent progress in tungsten metallic filament lamps, but, as far as I can see, it refers to only one lamp—the osram—all the way through. We know there are other lamps; we have seen them, and I have tested some of them; in fact, I believe there has been considerable progress made during the past few months in works outside the osram factory. There is only one paragraph in the paper I want to quarrel with, and that is on page 648, where Mr. Hirst says that "up to the present 40 to 50 c.p. is about the lowest unit that has been obtained in a commercial lamp, and some extraordinary development or discovery will have to be made before that candle-power can be largely reduced." I absolutely deny that statement. The British Westinghouse Company are at the present moment selling 230-volt 32-c.p. lamps, and these can be bought on the market; and I have very good reason to know that in a short time high-volt 25-c.p. tungsten filament lamps will be sold and will be a stock line. If we can have high-volt tungsten lamps to run on high-volt circuits, I do not think it is necessary to say very much about running them in series, because in ordinary house lighting two 16-c.p. lamps are needed to light a room, which could be substituted for a 32-c.p. metal lamp, so that there is no need to bother about running them in series. Mr. Hirst refers to the blackening of lamps, which he thinks may possibly be caused by the vacuum not being quite as it should be. I know for a fact that any lamp which is not properly exhausted will blacken immediately, but I have never yet met a lamp that has gone black which has been properly exhausted. There is a good deal of credit due to the people who have invented this metallic filament, but a good deal more has to be done besides making the filament. If the lamp is not properly made afterwards, there will be no end of trouble, and I am sure Mr. Hirst or Mr. Wilson appreciate that. Mr. Lowden.

Mr. C. H. WORDINGHAM: I should like to express my conviction that the metallic filament is a blessing, and only a blessing, to the industry. I think that to hear central station engineers talking about raising the price to keep out their greatest friend is painful in the extreme. The people to get a revenue from are the people who are using gas, and the only possibility of getting them is by some such epoch-making invention as this, which cuts the consumption down to one-third. Only those who have run central stations know how impossible it is to get consumers, unless they can show them that a low price will be charged. There is an ample field to go for; we have not yet obtained anything like a decent proportion of possible consumers, and I am positive it is the metallic filament lamp which Mr. Wordingham.

Mr. Wordingham.

will enable us to occupy that field. There is one more remark I should like to make, and that is that I think inventors might devote their attention to doing for the osram lamp what has been done for the Welsbach filament—namely, invent a simple and effectual anti-vibration holder.

Mr. Gaster.

Mr. LEON GASTER: I should like to say a word as regards Mr. Hirst's tables showing the economy to be derived from the use of osram lamps, on the basis of a certain initial cost, efficiency, and life. These tables are only correct under certain conditions—whether or no, for instance, lamps prematurely blackened, indicating defective manufacture, are replaced by the lamp-makers free of charge. Does Mr. Hirst mean to imply that the Company will actually exchange over the counter any lamps which are prematurely blackened in this way for new ones?

Next, as regards breakage in transport. As Mr. Hirst truly says, great progress has been made in the packing of large quantities of lamps, but it is in the case of small packages that breakages mainly occur. What responsibility, therefore, are the Company prepared to assume under these conditions? If the small consumer is to bear the entire cost of such breakages, Mr. Hirst's table will quite fail to represent the value of the metallic lamp to him, especially in cases where the price of current is comparatively low, the saving caused by the reduction of current is more than counterbalanced by the additional price of lamps and breakages.

In this connection I should also like to point out the necessity for seeing that detailed instructions are given to the contractor, and, through him, to the consumer, as to the best method of using the lamps. The value of the lamp can be more appreciated if it is properly treated. I am particularly pleased to note that Dr. Bell, Mr. Harrison, and several other speakers to-night have dwelt upon the necessity for softening the high intrinsic brilliancy of metallic filament lamps, and have referred to the fact that their greater efficiency enables us to bear without flinching the relatively small loss in light caused by the use of suitable diffusing shades. I have also expressed this opinion more than once in connection with metallic filament lamps, and hope it will receive due attention.

I feel we must congratulate the General Electric Company on the enterprising spirit which they have shown in undertaking the manufacture and sale of the osram lamp in this country, but it must be recognised that there are many other lamps now in the market claiming the same efficiency and the same life, of which Mr. Hirst's paper makes but brief mention. Is Mr. Hirst as yet prepared to give us any information regarding the patent position?

Lastly, we can only express our admiration at the immense energy and deep scientific knowledge displayed by the inventors and lamp-makers in the production of a serviceable metallic filament lamp and the recent improvement in its manufacture.

To my mind the use of transformers with metallic filament lamps,

though convenient at present, is only to be regarded as a temporary expedient, until the higher voltage and low-candle-power lamp is available, which may not be very long. Mr. Gaster.

Mr. J. S. RAWORTH: I remember the time when 25s. was paid for carbon filament lamps, and when the box was opened half of them were broken. Therefore, I wish to say to Mr. Hirst that even if there is a little fragility in his new lamps he need not be downhearted about it, because this has been cured with regard to the carbon lamp, and, no doubt, it will be cured with regard to the osram lamp. I am rather annoyed that Mr. Drake says that we do not use our lamps with sufficient intelligence, but at the same time I think that this is partly true. In my own drawing-room I have six lamps which have been there for ten years. If, however, I thought that the lamps were using more current all the time, then I would have them down to-morrow, even if I had to send for the gasfitter to do it. Twenty-five years ago, when the "Swan" lamp came out, I read a paper before one of the scientific societies of Manchester upon the electric light of the future, and pointed out that for every ton of coal they were then burning under their boilers to produce electric light only half a pound of it eventually appeared in the shape of light. I have forgotten how I obtained the data for this calculation—it may have been by weighing glow-worms. The fact remains that they have been going on for twenty-six years, and have been burning three times as much coal under their boilers as they should have done, and to those who have spoken of giving the carbon filament lamp a chance my answer is that it has none. The manager of one of the largest lamp factories in this country came to me the other day and said that he must have a metallic filament lamp because he could not sell carbon lamps. This was a very good reason, and I do not think there is a better one in the world. Mr. Raworth.

Mr. HIRST (*in reply*): I feel very much flattered with the kind reception which has been accorded to my paper and with the excellent contributions to the discussion. First of all, I wish to say that I tried in my paper to keep the manufacturer in the foreground and the trader in the background; but the questions that have been put to me, and the points that have been raised, necessitate an answer being given in my capacity as a trader. Mr. Gaster and others put to me questions which I can only answer in the way that has been indicated by Dr. Louis Bell. We are not very well organised in this country for introducing a new, delicate, scientific apparatus. In America and Germany manufacturers are station engineers as well; they are traders in direct contact with the consumers, and they can produce a new thing carefully throughout from the beginning to the end. We have to reckon here with a different state of affairs, and that is why one meets with difficulties that are prevailing to a less degree in other countries. That is why I first of all suggested that central stations should try and take the matter up; but what was the answer of the central station engineers? "We cannot fall out with the contractors; it is their business." Surely, if anybody cannot afford to fall out with Mr. Hirst.

Mr. Hirst. the contractors it is myself. Contractors have got into the way of considering a lamp as a lamp, and, in spite of all advice, they do not take anything that comes from a supplier as serious. We would like to sell shades with the lamps, as is the practice in the United States, as Dr. Bell mentions. We have various ideas as to how to overcome this difficulty of "fierce light," but we cannot get at the consumer. We have told the contractors, "The lamps break if you put them roughly on the table, and if you jerk them when you put them in the switch-holder"; we have told them that they must not be burnt upside down, or in this or that position, but how few contractors are organised to inform the consumer accordingly. It is exactly the same with regard to series running; even station engineers at the beginning did not take our instructions as serious. Therefore, a lot of these complaints are due, not to the make of the lamp, not to the way it has been introduced, but to the awkward trading conditions existing in this country. When experience has taught the consumers—that is to say, when the public have paid for it—then they will believe. Whenever Mr. Gaster rises to speak, he contributes to the gaiety of nations, and he reminds me that I promised to be liberal with regard to blackened lamps. We have been liberal as far as we know, and all the leading contractors will bear me out in that; but how many small contractors are there who had blackened lamps exchanged by us who do not think it necessary to exchange them again for the customer? I do not say that in an unkind way; they do it as a matter of business, and we have no power to control them; but I wish to assure you, in all earnestness, that the claim for blackened lamps is an absolutely negligible quantity. I am surprised that has been mentioned at all. At the initial stages of manufacture a few mistakes occurred, probably due to inexperienced labour; but since then such precautions have been taken that, to my knowledge, no instances of blackening have occurred in recent deliveries.

Mr. Harrison spoke about drawing tungsten, and various speakers have referred to certain matters connected with the industry of metallic lamps as State secrets. Needless to say, if tungsten could, according to our knowledge, be drawn at high temperature into wire, I would have put it in my paper. It will be very interesting to notice whether the patent which exists will prove of commercial value; I cannot give any definite information on that point. As regards series running, it is perfectly correct that the lamps are paired in steps, with a maximum possible variation of $\frac{1}{100}$th of an ampere, and I can only say that our experience amply proves that we are quite justified in adhering to this standard. Series running has proved a success all along from the moment it was properly understood. If I say that series running will have to continue, because I am afraid no low candle-power high-voltage lamps will come on the market at an early period, I say so because of what I know as a manufacturer. Twice the number of filaments are necessary for a 200-volt lamp than for a 100-volt lamp, and I fail to see how, with the present methods, we can get a smaller unit of light. If,

however, there are other methods, I think it will take some considerable time before these methods will be introduced. That is my opinion. I wish the Institution to know that it is no use saying that in a month, two months, six months, or twelve months, high voltage low candle-power lamps will be a marketable commodity. We ourselves—when I say "we," I mean the allied companies on the Continent, who now make millions of lamps—have no idea how a lamp can be commercially made with an appreciably lower unit at the same efficiency. I have seen 25-c.p. 200-volt lamps, but the price would not be a commercial one at all. With regard to what has been said about the question of breakage, I can only say that it is quite an exaggerated idea that the lamps break unduly. We introduced a 5 per cent. breakage allowance for all who buy these lamps. We have recently offered to exchange all lamps that are broken, but of course we will not give people the 5 per cent. breakage as well; and I do not know of a single instance in which the user took advantage of that offer. That is, after all, the best proof that the breakage cannot be so terribly high. I am convinced that the breakage has been more due to the careless way of opening the packages and handling the lamps when they arrive than to actual breakages in transit. Mr. Hirst.

I will now answer Mr. Handcock's questions as to why I use Hefner candle-power. I do this for the reason that the lamps come from countries in which Hefner candle-power is generally used. The figures are given in all official tests that exist, and I did not wish to introduce all at once other figures which are not familiar, and might lead to complications. I have no doubt that in due course all these lamps will be dealt with in English candle-power, though, personally, I must say that if I can prevent these lamps being sold by candle-power at all, I should like to do so. I should like to classify these lamps by watts, as I think Dr. Bell said is done in America, where they are sold as 100-watt, 60-watt, and 40-watt lamps, and not by candle-power.

Dr. BELL: They are rated in watts, but the candle-power is distinctly part of the rating. They are understood to be run at 1¼ watts per English candle. Dr. Bell.

Mr. HIRST: I think we shall have a very good case if, when the Standards Committee goes into this matter, we stick out for watts. As to Mr. Campbell Swinton's remarks with regard to the question of the white bodies at a high temperature beating the black bodies so far as the radiation is concerned, I do not suggest that I make this statement on the strength of my own experience. The information has been given to me by the inventors of the incandescent gas mantle and those who have been working on that theory, and, as the collector of that information, I thought it wise to give it to this meeting. Mr. Hirst.

With further reference to Mr. Harrison's allusion to a patent of the American General Electric Company, in which they propose to make filaments by heating tungsten up to a temperature below that of oxidation, and thus making it ductile, I simply want to say it will have to be proved whether it is a practical process.

Mr. Hirst.

Mr. Drake put the question why metal lamps are stated to have a longer life in winter than in summer. I wish to say that though I have heard remarks of this kind repeatedly, it has never yet been authentically proved. I can, however, conceive that this is correct, on account of the adverse influence of higher temperature upon incandescent lamps. It is known, for instance, that metal filament lamps, when enclosed in water-tight fitting without any ventilation holes whatsoever, have a shorter life than in the open atmosphere; and with all street lighting fittings I recommend to have a hole drilled in the outer globes to ensure a certain amount of ventilation, which remedy has been found absolutely satisfactory. It increases the life of the lamp to a remarkable extent. Apart from this fact, it has been proved by experiments (not only on osram lamps, but on any other lamps, that is, carbon filament lamps as well), that the life is to some extent dependent upon the temperature in which the lamps have to work.

With regard to Mr. Drake's remark comparing the cost of acetylene with that of low voltage installations, such as we have put on the market in connection with small country house lighting plants, I do not quite agree with his figures, inasmuch as I think that electric light with low voltage installations will work out even at a lower price than 2d.

The question brought up by Mr. Bell, whether it would be more advisable to run osram lamps at 1½ watts per candle (English) or 1 watt per English candle, is one which is difficult to answer generally, because it really depends upon the percentage of the total cost of lighting which is represented by the lamp cost, since it is natural that the lamp with the highest efficiency (even if of slightly shorter life) is preferable on circuits with high cost of current per unit, while a slightly less efficient lamp with a longer life will prove more economical on circuits with lower cost per unit.

The Osram Company have made comparative tests, showing how the life of the lamp varies when run at different figures of efficiency (watts per candle), and the present lamp is the outcome of these tests, carefully considering the average cost of electricity, and thus ensuring best all-round conditions for the lamp.

Considering the many authentic proofs and tests we have, showing that a large percentage of lamps burn 2,000 hours and more, there does not seem any reason to go away from the efficiency arrived at.

With regard to Mr. Bell's remark that he has heard of a lamp with a consumption of ½ watt per candle, I may state that the osram lamp can be run at some such efficiency, but of course the useful life would then be very much less. The rumour has probably emanated from some laboratory where a lamp ran at the efficiency mentioned, but no life tests were taken. The experiment, of course, is of theoretical interest, but of no practical value whatsoever.

Mr. Handcock points out that if one compares carbon filament lamps with osram lamps, one should theoretically take into consideration the mean spherical candle-power, not the horizontal candle-power. I quite agree with him. In practice, however, it will be found that the

difference is a very small one; though immediately vertically under the lamp the light emitted by the tungsten lamp is, as I quite agree, small, a perceptible amount is already reached at an angle of 7° from the vertical line. This, for all practical purposes, of course, is quite sufficient. Mr. Hirst.

I quite agree with Mr. Handcock that too little importance is attached to the fact that one should not really compare efficiencies of lamps at the beginning of their life, but when judging them, should take into account the average efficiency during their life. The osram lamp, of course, will show up better still in this comparison, because, while the efficiency of a carbon filament lamp with an initial watt consumption of, say, 3·5 watts per candle, increases in 1,000 hours, say, to 4·2 watts per candle (that is, at least, 20 per cent.), the corresponding increase with a tungsten lamp will be on an average about 6 per cent. While, therefore, the average efficiency of the osram lamp is about 3 per cent. less than the initial, the average efficiency of the carbon filament lamp will be, at least, about 17 per cent. less.

Mr. Lowden reproaches me with only giving particulars of lamps made under the Osram and Just-Hanaman process. I think, if he reads a little more carefully what I say on page 641, he will find that his remarks are not quite correct, and that, after going into the patent question, I say, "I believe I am right in maintaining that of the multitude of processes that have been applied for and tried since the first application of the Deutsche Gasglühlicht Aktiengesellschaft and the Just and Hanaman patents, these two alone have, during the last two years, produced to the world commercial and useful lamps." I therefore limit myself to these and refrain from dealing with lamps which are not yet out of the experimental stage, nor even those that are made after patents of doubtful validity.

I quite agree with Mr. Lowden that there are some other lamps as well on the market. I have seen some, too; but where Mr. Lowden is most wrong is, that he anticipates those lamps being made by independent processes, whilst I have definite information to show that they have been made with disregard of the patents of the Deutsche Gasglühlicht Company and Just and Hanaman.

Mr. Lowden states that 230-volt 25-c.p. lamps are on the market. Of course, this is a statement which anybody can prove, or rather disprove, himself. I do not mean, of course, that it is impossible to make one 25-c.p. lamp (Hefner candle) for 230 volts; but I am always speaking of manufacturing in commercial quantities lamps with a commercial life and with a commercial price, which is, of course, the only thing which is of real interest to us.

In conclusion, I thank the members for the attention they have paid to this paper.

On the motion of the President the thanks of the meeting were unanimously accorded to Mr. Hirst for his valuable paper.

The meeting adjourned at 9.30 p.m.

POLYPHASE INDUCTION MOTORS : THE CHOICE OF TYPE.

By GEORGE STEVENSON, Associate Member.

(*Paper received from the* GLASGOW LOCAL SECTION, *February 26, and read at Glasgow, April 14, 1908.*)

Experience in the industrial application of electrical energy has shown that it is desirable to adhere as closely as possible to the following main considerations in the lay-out of a motor installation, namely :—

1. The elimination of all energy-consuming links between the motor and its work.
2. The adoption of standard sizes of motors.
3. The use of as few such sizes as is consistent with economy in the initial outlay and in the ultimate operation of the plant.

These considerations are now so universally recognised as to make it unnecessary to examine them in detail. The author ventures to suggest, however, that there is a fourth point worthy of more careful study, namely, the attainment of greater simplicity in the electrical part of the equipment. This desirable end, in the author's opinion, can now be more easily arrived at, on account of the greatly extended use of 2- and 3-phase motors for general industrial purposes. The present paper is based on experience gained in the conversion of various classes of machines from steam to electric driving, with special reference to the question of simplicity in the motor and starting gear in connection therewith. The engineer engaged in the application of induction motors has two classes to choose from, namely :—

(*a*) Those with short-circuited or "squirrel-cage" rotors.
(*b*) Those with slip-ring or wound rotors.

Naturally, the first thing to consider is the comparative cost of the two classes of motor, since, other things being equal, the choice will invariably fall on the cheaper machine. Curves A and B (Fig. 1) for a standard line of 50-$\sim$ 500-volt motors, show that the advantage in this respect is on the side of the squirrel-cage type. The prices are taken from makers' lists, and do not include starters. If these latter are allowed for, then the squirrel-cage motor comes out still cheaper in sizes up to and including 50 H.P., because, as will be shown later,

the starting gear for this type is much simpler and less expensive than that required for the motor with wound rotor (curves A_1 and B_1 Fig. 2). Above 50 H.P. the prices of both types are practically the same. It should be mentioned that the motors here referred to were chosen with speeds to suit their individual outputs. Thus the 5-H.P.

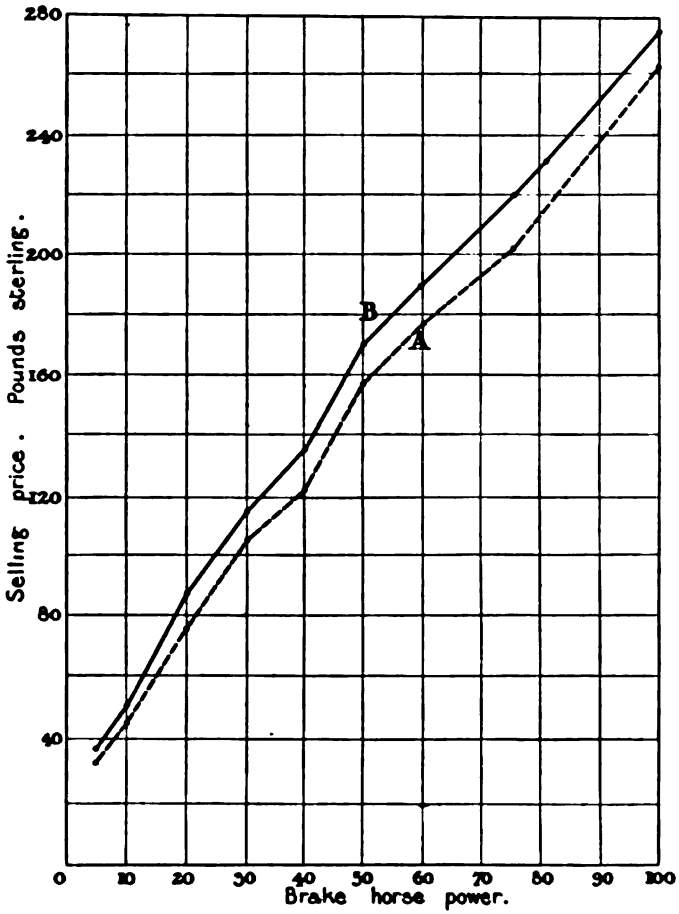


FIG. 1.

machine is designed for a synchronous speed of 1,000; the 50-H.P. for 500, and the 100-H.P. for 500 revs. per minute, these being about the usual speeds which would be adopted in practice.

With respect to the relative weights of the two types there is not much difference, the squirrel-cage machine being only about 3 per cent. lighter. The efficiencies, power factors, and overload capacities,

however, are slightly higher for the squirrel-cage type, but the outstanding feature in the general comparison is undoubtedly the extreme simplicity of the revolving element (Fig. 3), which consists of nothing more than a number of copper bars parallel to and surrounding the shaft

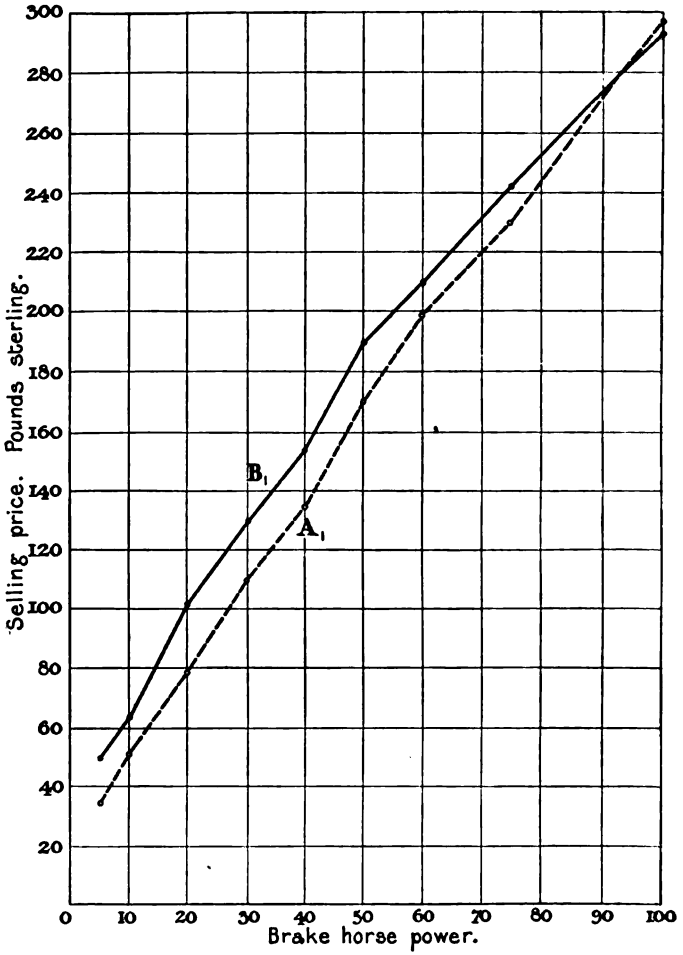


FIG. 2.

and embedded in an iron core, with their ends connected by rings. As compared with class (*b*) rotor, Fig. 4, it will be seen that the absence of moving contacts in class (*a*) machine—which makes it absolutely sparkless, and therefore specially suited for operation in mines, or mills where dangers from explosive mixtures or gases exist—

is a conspicuous advantage. Moreover, the robust construction of the rotor, due to the entire absence of coils and their attendant insulation, is a characteristic of this class of motor which appeals strongly to the mechanical engineer. It would therefore appear from the foregoing comparison that class (*a*) motor should be installed in every case, but, unfortunately, it has the serious disadvantage that unless suitable precautions are taken on starting up, a somewhat excessive current is drawn from the line, and if the starting current is reduced, then the starting torque is diminished in proportion. There are several excellent methods of reducing the starting current to a reasonable figure, but nevertheless it is still the practice of some supply authorities to prohibit entirely the connection to their system of squirrel-cage

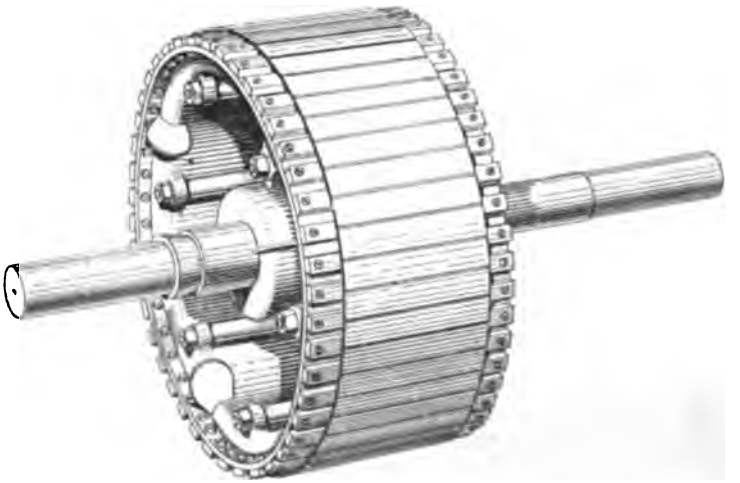


FIG. 3.

machines, except in the very smallest sizes. As will be shown later, the views of the various power companies differ considerably in this respect.

In order to ascertain for himself what could be done with standard motors, the author some time ago made a series of tests to determine—

1. The current taken from the line at starting in terms of the full-load current.
2. The resulting torque.

The machines tested were all built for operation on a 500-volt, 50-~ 3-phase circuit. The figures given in Table I. were obtained by passing a current through the stator at about 130 volts pressure, while the rotor was prevented from rotating, since it would obviously be unsafe to subject the stator to the full working pressure under such

conditions. The amperes at 500 volts were then calculated from the test results, on the assumption that the current is directly proportional to the impressed E.M.F.

TABLE I.

Size, B.H.P.	Full Load.	Current at Standstill (Starting) at 500 Volts.	Starting Current in Terms of Full-load Current.	Remarks.
	Amperes.	Amperes.		
2·5	3·00	18·0	$\frac{18}{3}=6$	
5·0	6·25	23·5	$\frac{23·5}{6·25}=3·75$	Motor switched straight on to line, stators Δ connected.
11·0	13·00	75·0	$\frac{75}{13}=5·75$	
33·0	37·00	168·0	$\frac{168}{37}=4·55$	

On account of the fact that alternating current plant is usually designed for somewhat low magnetic saturation in the iron, and moreover as the saturation is particularly low in the test referred to above, this assumption may be taken as being sufficiently accurate for all practical purposes. It will be seen from an inspection of column 4 that squirrel-cage motors, if switched straight on to the line, will take from 4·55 to 6 times their full-load currents. The adoption of this method of starting is, therefore, out of the question, except in the very smallest sizes, say up to 10 B.H.P., on account of the violent disturbances which would result to the supply pressure. Moreover, the power factor under these conditions is of the order of 0·4, and this causes excessive idle or "wattless" currents in the line, thus affecting objectionably the pressure regulation of the system.

In order to determine the starting torque two additional tests require to be made, and recourse must then be had to the circle diagram. Since the process involved is somewhat lengthy, the figures for one machine only have been worked out in detail, namely, the motor rated at 33 H.P. The complete construction is given in Appendix I. at the end of the paper, from which it is found that the starting torque for the machine in question will be about 1·13 times the full-load torque, and this with a starting current equal to 4·55 times full-load current.

These figures may be taken as being fairly representative of good modern machines, although by a special design of rotor it is possible to improve very considerably the results given above. Having ex-

amined the defects of squirrel-cage machines, so far as their starting capabilities are concerned, it remains to be seen to what extent these can be overcome. The problem resolves itself entirely into methods which will permit of :—

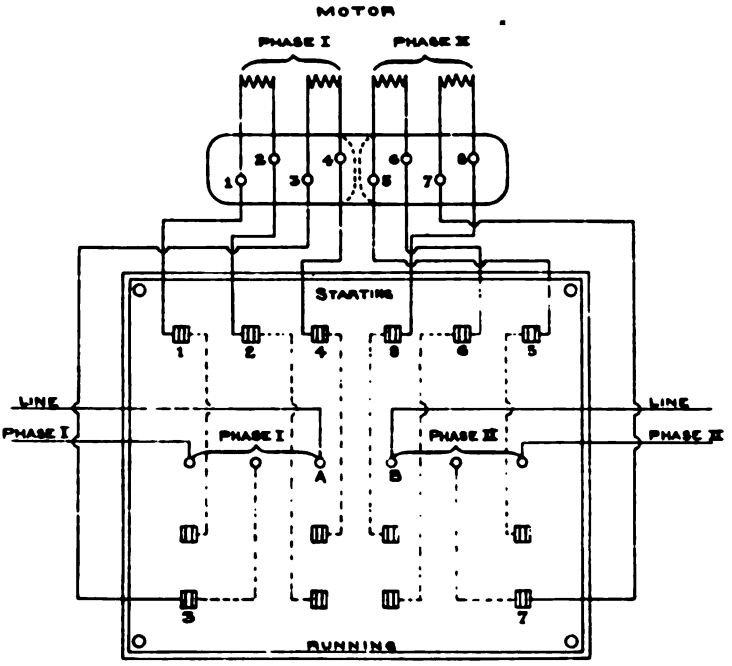


FIG. 5.—Connections of Starting Switch for 2-phase Squirrel-cage Induction Motors.

1. A reasonable starting current being drawn from the line.
2. Such arrangements in the disposition of the motor in relation to its work as will enable it to start under comparatively light load conditions, say, not exceeding half full-load torque, or alternatively, if the above conditions cannot be met.
3. The adoption of a special form of "high torque" rotor.

1. In the author's view, one of the most attractive methods of starting induction motors, when the operating conditions of the driven machinery permit, is to keep all the motors coupled up to the line and start them simultaneously with the engine and generator. This method, however, cannot be used except where the installation includes the generating plant. The current taken at starting is very small with this arrangement, but it would appear to be necessary to have separately driven exciters, in order that the main generator may

be started from rest with full voltage on the field. Facilities for starting any individual motor would also have to be provided, since it would obviously not be feasible to shut down the whole plant and start afresh in the event of one motor being put out of action. So far as the author knows, the system has not been adopted in this country; the only example which he has heard of being that of a cotton mill in Georgia, United States.

Viewed from the standpoint of simplicity, perhaps the next best method of starting class (*a*) machines is that patented by H. S. Meyer. The method adopted in the case of 2-phase motors is to connect the stator windings in series at starting (Fig. 5), so that the voltage per

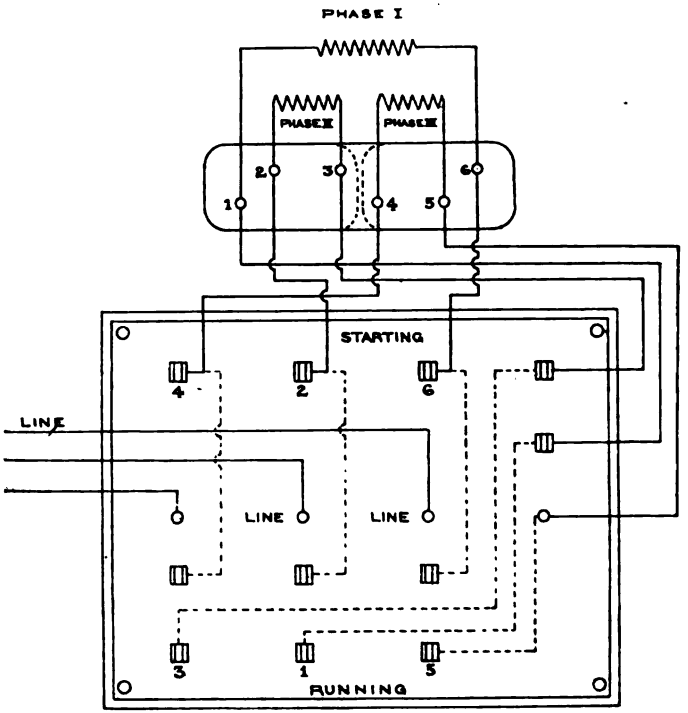


FIG. 6.—Connections of Starting Switch for 3-phase Squirrel-cage Induction Motors.

phase is only half of the line voltage, and the starting current and torque are reduced to one quarter the value they would have if full voltage were impressed at the motor terminals. After the machine has run up to speed the switch (Fig. 8) is thrown over to the running position, when each phase receives its full pressure. In the case of 3-phase motors they are designed for running normally on



FIG. 4.



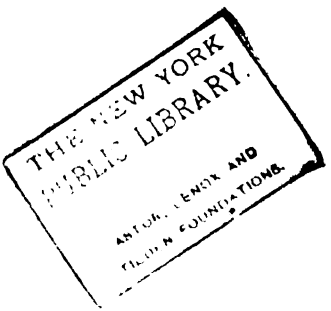
FIG. 7. Starting Switch for 3-phase Squirrel-cage Motor.



FIG. 8.— Oil Immersed Starting Switch for 2- and 3-phase Squirrel-cage Motors.



FIG. 11.—Starting Compensator with Oil Break Switch for large Squirrel-cage Motors.


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delta connection, the starting being effected by switching on to the line with the windings connected in Y grouping (Fig. 6). By this means the voltage per phase at starting is only $\frac{1}{\sqrt{3}}$ or 58 per cent. of the line voltage. The starting current and torque are, of course, also reduced; for instance, taking the 33-H.P. machine to which reference has already been made, the starting current would be only one-third of that taken if motor were switched straight on—that is, $\frac{4{\cdot}55}{3} = 1{\cdot}5$ times full-load current. The starting torque being proportional to the square of the voltage would be reduced in the ratio $500^2 : \left(\frac{500}{\sqrt{3}}\right)^2$—that is, as 3 : 1, or one-third of its value at full load. The author has used these methods for 2- and 3-phase machines up to 50 H.P. with excellent results. The switch (Fig. 7) is of the air-break type for motors up to 20 H.P. on a 500-volt circuit. Above this size it is good practice to use an oil-break switch (Fig. 8). As a practical example of what can be accomplished in the way of starting with this device, mention may be made of a 10-H.P. machine which starts easily a 3-in. diameter line shaft 75 ft. long, having 12 pulleys and belts at intervals along its length, and running in 12 ordinary bearings. Nine vertical drilling machines and three pairs 12-in. emery wheels are driven from the motor through this line shaft.

It is interesting to notice—turning for a moment to a side issue—that power users are at last beginning to realise the effect of shafting and other frictional losses on their bills for current, with the result that, in new equipments at all events, high-class roller bearings are taking the place of the old solid pattern. The item of extra first cost is always a stumbling-block in the introduction of new methods, but just as the lighting consumer has become educated up to the advantages accruing from the use of high-efficiency lamps, and is prepared to pay a good price for them, so also the power user will eventually recognise that low initial outlay is not always to his advantage. The saving in power effected by the adoption of roller bearings is stated by the makers to be from 10 to 25 per cent., and they claim that the extra initial cost will be returned in the first year's operation by the saving in power alone. The author is unable to say to what extent these statements are borne out in actual practice. Doubtless the discussion will elicit some figures on this point.

With this brief digression, and returning to the subject under consideration, mention may now be made of what is probably the commonest method of starting squirrel-cage machines, namely, the use of the so-called compensator or auto-starter. The underlying principle of this type of starter will be understood by an inspection of Fig. 9. The arrangement is equivalent in effect to a step-down transformer. When the switch is placed in the starting position, the voltage across the motor terminals is only a fraction of the line voltage. After the motor has reached normal speed, the switch is thrown into the

"Running" position, and the motor is then supplied at the full-line voltage. The compensator windings for a 3-phase motor consist of one coil for each phase, with each coil placed on a separate leg of a

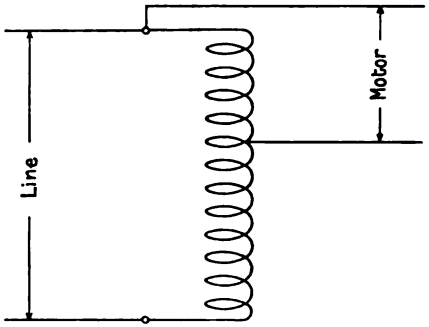


FIG. 9.—Principle of Compensator.

laminated iron core. Each coil is provided with several taps, so that a number of sub-voltages may be obtained, any one of which may be selected for permanent connection to the switch for starting the motor.

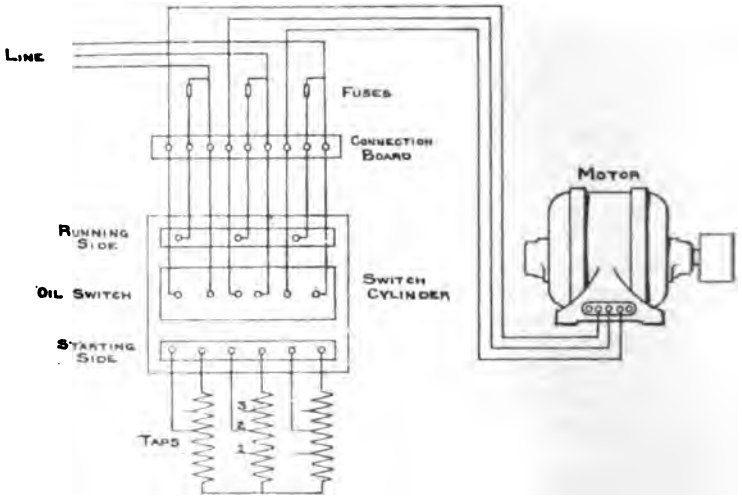


FIG. 10.—Connections of Starting Compensator to 3-phase Induction Motor.

according to individual requirements. The three coils of the 3-phase winding are connected in "Y," the line to the three free ends of the coils, and the starting connections of the motor to the taps (Fig. 10). To meet various requirements, compensators for standard motors of 5, 10, and 15 H.P. are usually provided with taps for starting the motor at

40, 60, and 80 per cent. of the line voltage, with respective line currents equal to 16, 36, and 65 per cent. of the current that would be taken by the motor if no compensator were used. For larger motors compensator taps should be provided giving potentials equal to 40, 58, 70, and 85 per cent. of the line voltage, and respective currents equal to 16, 34, 50, and 72 per cent. of the current that would be taken by the motor if it were started direct from the line. The proper tap for giving

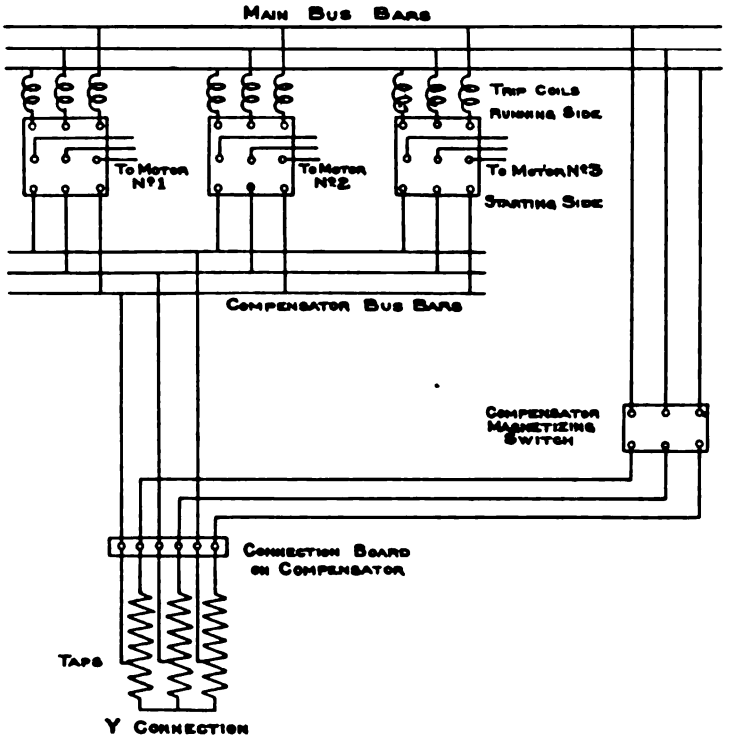


FIG. 12.—Connections for starting a number of 3-phase Induction Motors from one Starting Compensator.

maximum starting effort without causing an objectionable voltage variation in the supply circuit may readily be ascertained by trial, and permanently connected, at the time of installation.

A defect of the ordinary pattern of compensator fitted with the usual throw-over switch is that the motor may be switched straight on to the line by a careless attendant, thus causing a rush of current, which it is the object of the compensator to avoid. The type shown in Fig. 11 is provided with a latch, so arranged that the lever at "Off" can be thrown only into the starting position (backward), and can be thrown

from thence into the running position (forward) only by a quick throw of the lever. The starting switch, as a rule, is fitted in the case containing the auto-transformer, and is connected direct thereto. By separating the switch from the coils, a number of motors may be started from one auto-transformer, thus saving the expense of installing individual compensators. A throw-over switch is provided for each motor to be started, and a 3-pole compensator magnetising switch. Only one motor would be started at a time, and each motor switch must be thrown into the running position so soon as the motor has come up to speed. When all the motors are started the compensator magnetising switch would be opened. The diagram (Fig. 12) shows the method of connecting three motors in this way. The chief objection to the compensator as a starting device is its excessive cost, this being usually about one-third the cost of the motor. Furthermore, it has been found that under actual working conditions cases frequently occur of coils being burned out, due to the switch being left in the "Starting" position.

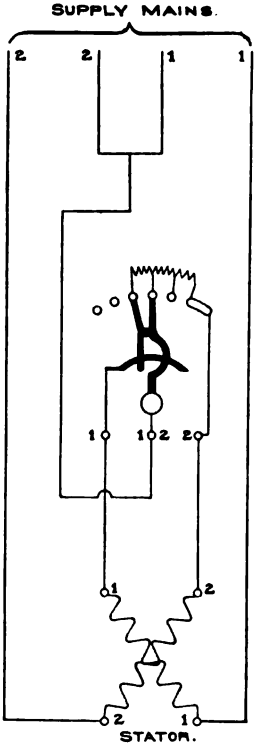


FIG. 13.—Connections of Starting Rheostat for small 2-phase Squirrel Cage Induction Motors.

Some makers use a resistance in the stator circuit for starting up, but the method is not advisable, since the current is only reduced in proportion to the reduction in the voltage, while the torque is reduced as the square of the voltage. The connections for a small 2-phase machine are given in Fig. 13.*

The foregoing covers the principal devices in use at the present time for starting up class (*a*) motors. Numerous attempts have been made to increase the starting torque per ampere, or "specific" starting torque of this class of motor, while preserving its characteristic features of simplicity and robust construction. Among the more interesting may be mentioned—

Boucherot's † three methods—use of component rotors, movable stator, and phase transformer.
Hobart † (utilisation of skin effect).
Zani † (use of inductance coils).

More recently Hunt ‡ has devised a cascade arrangement.

* The two switch levers are not *electrically* connected.
† Hobart's "Electric Motors," pp. 266–291.
‡ *Journal, Institution of Electrical Engineers*, vol. 39, p. 648, 1907.

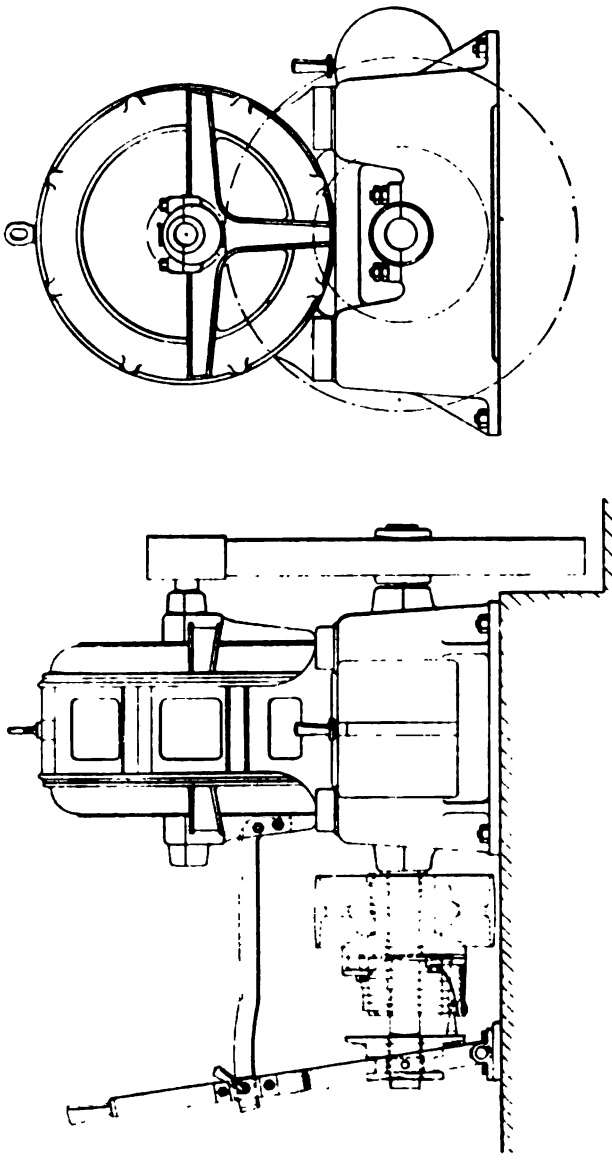


FIG. 14.—Application of Coil Friction Clutch.

2. None of these methods, however, with the possible exception of the last named, appear to have attained to any degree of commercial importance, in this country at least; and, in the author's view, the problem ought to be approached from the opposite standpoint—that is to say, that, instead of designing the motor to suit the conditions, arrangements should be made to permit the installation of the ordinary simple squirrel-cage machine.

An example of what is meant is shown in Fig. 14. Here the object was to drive a mortar mill—a class of drive which, as most engineers know, is somewhat troublesome, both in regard to the starting and

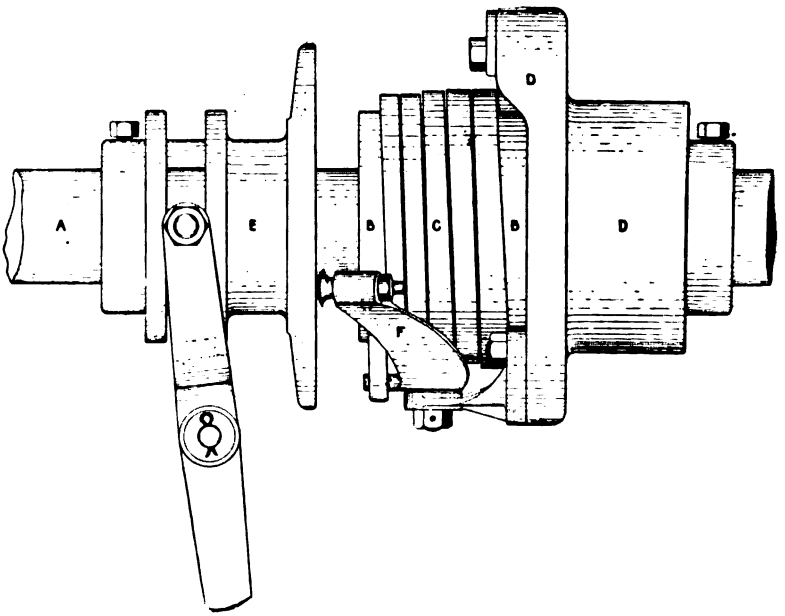


FIG. 15.—Coil Friction Clutch.

overload conditions. The machine was situated in a very dusty position in a foundry, and, after taking all the circumstances into consideration, it was decided to adopt a friction clutch in combination with suitable single reduction spur-gear, and a class (*a*) motor with "Y" delta starter. A word or two is necessary in regard to the clutch, which is of the "coil" type (Fig. 15).

The shaft A, which is driven by the motor, has keyed upon it the cylindrical drum B B, which is hardened and ground. Coiled round this cylinder is a steel coil C attached to the casting D D. This either carries a gear-wheel or belt pulley, or if the clutch is used as a coupling it is keyed on to a separate shaft. When it is desired to put the clutch in gear the loose collar E is moved towards the coil by means of a

lever, operated either by hand or screw; this in turn actuates the hooked lever F, which presses on the tail of the coil, causing it to wind gradually and tightly round the cylinder B. The advantages of this clutch are that it is easily made for all powers, even up to 2,000 H.P., and by operating the starting lever by means of a wheel and screw there is not the slightest shock when it is put into gear.

So far as the author is aware, no other clutches yet devised have been made up to such high powers, nor is their performance so satisfactory. Reference has already been made to the advantages of the squirrel-cage motor for mining work. The author's experience in this connection leads him to affirm without hesitation that this class of motor, whenever the conditions permit of its application, is superior to any other type. Of course, there are difficulties in the way of its application to the various power requirements of a coal-mine, but they can generally be overcome by suitable mechanical arrangements. Take,

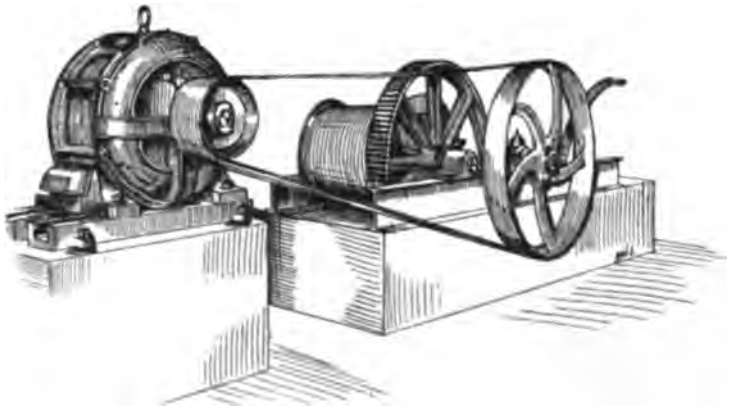


FIG. 16.

for example, the case of haulages. The three systems in general use—that is, direct haulage, main and tail haulage, and endless-rope haulage—can all be operated quite satisfactorily by means of squirrel-cage machines in combination with suitable clutches. Of these three systems the last named is the easiest to operate in this way, because it is not necessary to start and stop at frequent intervals. The speed of the motor can also be kept constant, since the gear is usually designed for a uniform rope speed of about 2 miles per hour. The best position for the clutch is direct on the haulage drum, because the motor can then be quickly relieved of its load should the tubs chance to come off the road. Practical mining engineers are agreed that clutches give a control over the haulage which is unattainable by other means. Examples—on a small scale—of the application of squirrel-cage motors

to direct and endless-rope haulage systems, in the manner just referred to, are shown in Figs. 16 and 17. The motors are of 15 and 40 B.H.P. respectively, and are started and stopped by an oil-immersed "Y" delta switch.

The various types of pumps in use for mining purposes can also be readily arranged for driving by this class of motor. In the case of 3-throw pumps, a by-pass valve can be fitted, thus enabling the motor to start up light. With respect to centrifugal pumps, which are now coming so rapidly to the front for high-lift duty, it is quite a simple matter to make provision for starting the motor

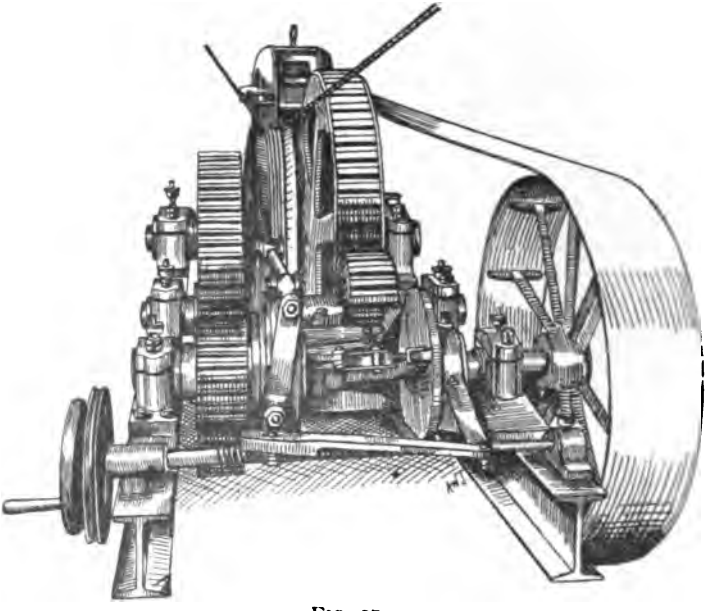


FIG. 17.

under light load. All that is necessary is to insert a sluice valve in the rising main near to the discharge side of the pump. By closing this valve, starting may be effected with about one-quarter to one-third of full-load torque. The author has used this method with motors of the squirrel-cage type up to 100 H.P. As regards coal cutting machinery, this class of work is probably the most difficult to tackle by any type of motor, not merely on account of the requirements at starting, but also because of the excessive vibration and overloads, and rough usage generally, to which such machines are subject. The squirrel-cage motor is peculiarly suited for these conditions, and is now largely used for driving the various types of coal-cutter. As regards the starting arrangements, some makers rely on the ordinary

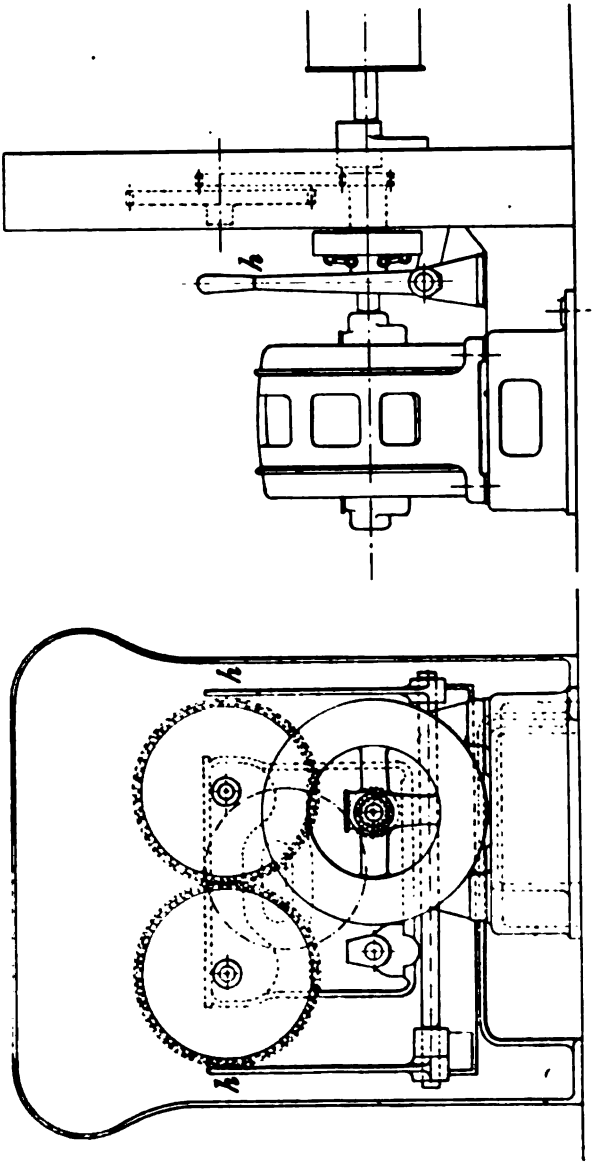


FIG. 18.

compensator only, without making provision for relieving the motor of load. Others adopt a suitable device to enable the motor to start up light. Any arrangement which permits the rotor to make several revolutions before taking up the load will help to reduce the evil effects on the supply voltage due to an excessive rush of current at starting. Such an arrangement has been devised by Holiday.* The motor is geared 2 to 1 on to a wheel which is free to make one revolution before moving the driving shaft, so that it makes several revolutions before beginning to drive the cutting-wheel. When the man stops the machine he runs the motor back to the starting-point by means of a

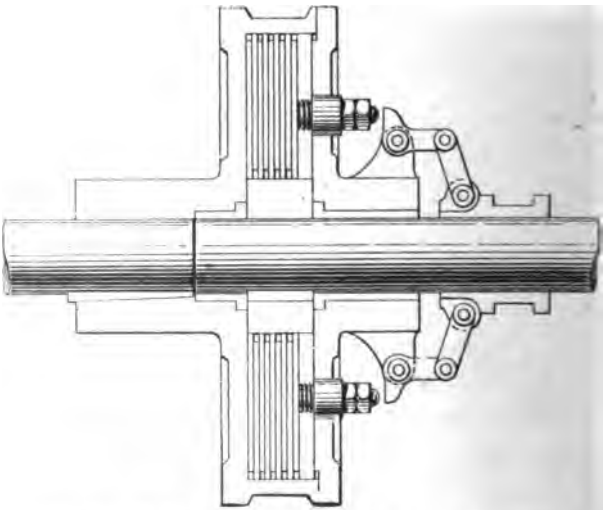


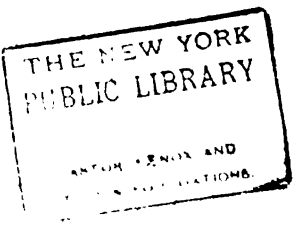
FIG. 20.—Hull's Patent Disc Friction Clutch Coupling.

reversing switch ; then, on starting forward again, the motor gets up sufficient speed to start the cutting-wheel. It may here be pointed out that the starting current is independent of the load on the motor. If the load is small the motor will accelerate quickly, if large it will accelerate slowly, or may not start at all, but the starting current is the same under all these conditions. Figs. 18 and 19 show the application of class (*a*) motors to the driving of textile plant. The motors are connected direct to the ring spinning frames by means of clutch couplings of the type shown in Fig. 20. Handles (*h h*), Fig. 18, operating the clutches are placed in convenient positions for the attendant. The motors are rated at 6½ B.H.P., and starting is effected by switching them straight on to the line. The starting switches will be seen in Fig. 19 mounted near the top of the framework.

* *Journal, Institution of Electrical Engineers*, vol. 30, p. 867, 1901.



FIG. 19.


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These few examples of the practical application of the simple form of squirrel-cage machine will show that the difficulties attending its adoption can readily be overcome. Other engineers who have been working on similar lines will doubtless furnish additional examples during the discussion.

3. In some cases, however, it is found that the ordinary form of low resistance rotor with copper bars does not meet the requirements. It can be shown that the starting torque of an induction motor is increased by an increase in the resistance of the rotor windings.* Hence by making the rotor bars of higher resistance, the specific starting torque may be increased. To take for example the 33-H.P. motor, to which reference has already been made, by making the rotor with 66 per cent. higher resistance, the starting current would be reduced by 3 per cent., and the starting torque would be increased to 1·75 times full-load torque. The increase in the resistance of the rotor naturally causes greater C^2R losses, so that this means a lower efficiency, but the difference is such as in many cases to be well worth the advantage gained in respect to the starting qualities of the machine. In the case under discussion, the efficiency would be reduced by 2 per cent. The power factor would be slightly increased, so that the reduction in the apparent efficiency—which is the really important point—would be slightly less than 2 per cent. The effect of resistance in the rotor is somewhat similar to its effect in the case of the armature of a continuous-current machine. In both cases the resistance is kept as low as possible, to insure high efficiency and a small drop in speed from no load to full load. It has just been stated, however, that the introduction of resistance in the rotor windings increases the starting torque and reduces the starting current. Hence a larger starting torque can be obtained by temporarily inserting resistances in the rotor. When the motor has reached normal speed, these resistances can be short-circuited, since they are no longer required.

This leads to a consideration of class (*b*) motor. Here the revolving element (Fig. 4) consists of a laminated iron core with a polar winding insulated and arranged similarly to the stator winding. The rotor coils are usually Y-connected, and their terminals taken through a hollow shaft to collector rings on which rest carbon brushes supported by the usual spring holders. By means of a rheostat external to the motor suitable resistances can be inserted in each phase at starting. The connections are shown in Fig. 21. The available starting torque with this type of motor can be anything up to the maximum, that is, normally about twice the full-load value, but in special cases up to three times. The starting current corresponds to about full-load current when starting with full-load torque, and proportionally more when starting with greater torque. In those cases in which no speed regulation is required, provision is usually made to short-circuit the winding in itself, instead of through the brushes and rheostat leads, so soon as the motor has reached normal speed. In some cases a brush-lifting device is also

* Appendix I., p. 698.

provided with the object of reducing the wear and tear on brushes and rings. In the author's view, however, this latter refinement is unnecessary for most ordinary purposes, and usually gives more trouble than it is worth. In fact, practically the only trouble the author has had with polyphase motors during some five years' experience has been due to slip rings and their accessories. It will be interesting to hear the views of others in this connection. One advantage possessed by the slip-ring machine is the ease with which its speed may be regulated. The method, however, is analogous to inserting resistances in the armature circuit of a continuous-current motor, and is open to the same objection on the score of its inefficiency. Furthermore, any change in the load is accompanied by a corresponding change in the speed. It will be seen from the foregoing considerations that the adoption of the squirrel-cage

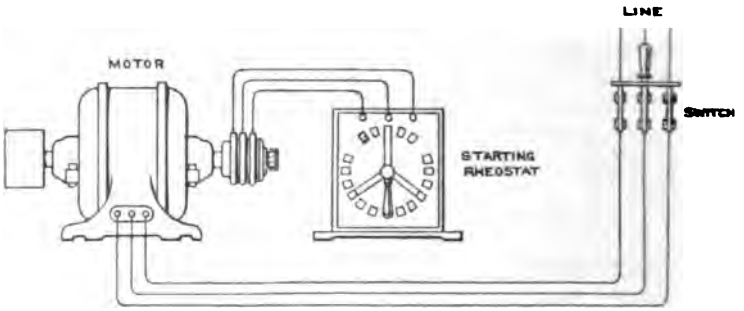


FIG. 21.—Connections of Starting Arrangement for 3-phase Slip-ring Induction Motors.

type of motor, whenever the conditions permit, would be entirely in accordance with the dictates of good engineering. Of course there are certain cases where it is not feasible to adopt this type, notably for crane work, although even here the author has seen successful examples of crane driving by means of squirrel-cage machines. When all is said and done, however, the choice of type, except in private plants, is subject to the approval of the supply authority. It therefore becomes necessary to ascertain to what extent the consumer is enabled to take advantage of the superior qualities of class (*a*) motor. Accordingly the author obtained the rules of the principal companies and corporations supplying polyphase current in the United Kingdom with respect to this point. The figures are given in Table II. One would naturally expect that the maximum size of class (*a*) motor allowed would be dependent in large measure on the station plant capacity, because in a private plant the total capacity of squirrel-cage motors, and the individual capacity of any one squirrel-cage motor, should bear a relation to the generating plant such that each squirrel-cage machine can be stopped or started at any time during normal working, without interfering with the running of the other motors on circuit.

Therefore these figures—for which the author is indebted to the *Electrical Times*, are also given in the table. It is interesting to notice, however, that this consideration does not seem to have much influence on the restrictions imposed, for, as will be seen from an inspection of the figures, company A, with a station plant capacity of 6,000 k.w., allows a motor of 100 B.H.P. against 50 B.H.P. in the case of company E, with a plant capacity of 20,000 k.w. Also company C, with a plant capacity of only 1,000 k.w., allows a motor of 20 B.H.P., whereas company D, with twice the plant capacity, restricts the current at starting to 1 ampere per B.H.P., and will not permit the connection to their system of class (*a*) machines. Doubtless the number and temperament of the lighting consumers on the mains are the determining factors. As a matter of fact, however, the author has found that the rules of the various power companies need not be too rigidly interpreted. The engineers are usually business men who are willing to meet their consumers as far as possible. An inspection of the table will show that the power companies are more favourably disposed towards the adoption of class (*a*) motors than are the various local authorities, and in this respect, and speaking purely from the power user's standpoint, they would seem to be doing better work. Moreover, the author ventures to affirm that local authorities are in a great many cases overburdened with rules and regulations, which must inevitably hinder the development of power supply. The question is of importance at the present juncture, in view of the inquiry held by the Home Office to deal with the rules and regulations concerning the application of electrical energy in factories. The power companies seem to be able to get along comfortably with a set of rules contained in a single sheet of foolscap. The local authority, on the other hand, appears to require protection to the extent of a bound volume of 30 or 40 pages. Among anomalies in the way of rules which the author has encountered, reference will be made to two only:—

(1) The power factor of any motor *must not fall below* 0·8.
(2) Before any application for power *can be accepted*, the name of the maker of the motor must be stated.*

With reference to (1), the curve (Fig. 22) for the 33-H.P. motor previously discussed shows that the power factor is a function of the load. The rule as it stands is equivalent therefore to the demand that the motor shall always be operated at a given output, which of course is absurd. With respect to rule (2), it is surely not within the province of the supply authority to interfere in this connection, and in any case the author fails to see that the rule serves a useful purpose.

Before leaving the subject of power factor the author would like to emphasise the importance of choosing a motor which shall not be too large for its work, because, as will be noticed from Fig. 22, the power factor falls off very rapidly with reduction in load. One of the points,

* The italics are the author's.

therefore, to which attention should be given when laying out a motor equipment, more especially if the installation is to have its own generating plant, is to endeavour to operate each motor at its rated output. In fact, no harm is done to a high-class machine by an occasional overload.

The overall power factor for an installation depends on the amount of attention which is given to the foregoing considerations in the initial stages of the scheme. In actual practice it is customary to assume a figure of 0·8 for general industrial plants and 0·75 for mining installations, although this must of necessity be a variable

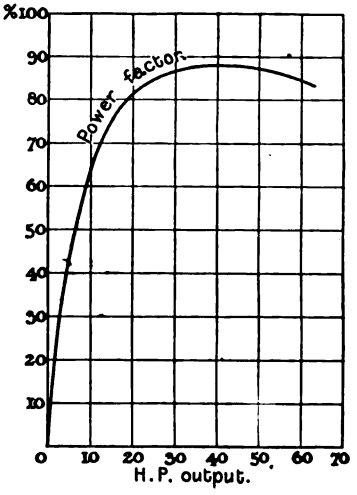


FIG. 22.

figure, dependent entirely on local conditions. The author's experience tends to show that it takes a load of a very steady nature, together with a very well laid-out plant, to attain a figure of 0·80 in actual everyday operation. This is probably only attained under the most favourable circumstances in a textile or similar plant.

In conclusion the author ventures to affirm that electrical engineers in general are too apt to attempt a solution of each and every problem by electrical means, and without sufficient consideration of the case in its mechanical aspects. As proof that his own practice is in accordance with his precepts he would mention the case of a large foundry and engineering works for the electrical equipment of which he was responsible. Out of a total of some 40 motors, aggregating about 500 H.P., only 4, or 10 per cent. of the total, were of the slip-ring type, the others being adapted to the various requirements by the mechanical arrangements outlined in the paper.

The author is indebted to some of the leading manufacturing com-

panies for particulars of their standard polyphase motors, and to the engineers of the various supply authorities who were good enough to furnish him with copies of their rules.

TABLE II.

Ref. Letter.	Largest Size Class (*a*) Motor Permitted. B.H.P.	Maximum Permissible Starting Current.	Station Plant Capacity. K.W.	Supply Company or Local Authority.	Remarks.
A	100	No stipulation	6,000	Company	Squirrel-cage machines installed wherever possible. No difficulties met with in supplying power to 100-H.P. machines of this type.
B	10	1½ times full load for class (*a*): full load for class (*b*)	7,500	Local Authority	All squirrel-cage machines must start on loose pulley.
C	20	No stipulation	1,000	Company	The installation of squirrel-cage machines is encouraged as much as possible.
D	None allowed	1 ampere per B.H.P.	2,000	Company	All motors must be of slip-ring type.
E	50	1½ times full load	20,000	Company	In exceptional circumstances larger sizes may be permitted.
F	Depends on nature of load	1½ times full load	10,440	Local Authority	All motors must start up on loose pulley except under special conditions. No motor of less than 6-B.H.P. to have slip rings.
G	10	No stipulation	3,500	Company	Enforcement of hard and fast rule would often lead to loss of consumer, owing to cost of class (*a*) being so much less than class (*b*) machines, therefore each case is judged on its own merits.
H	5	¾ full load	2,250	Local Authority	They find class (*a*) motors detrimental to the supply to other consumers.
K	50	No stipulation	8,000	Company	—
L	4	1½ full load	4,500	Local Authority	All motors above 3-H.P. must start on loose pulley.

* Revised since table was prepared. New rules permit class (*a*) motors up to 50 B.H.P. provided starting current does not exceed 1½ times full load.

APPENDIX I.

Experimental Derivation of the Circle Diagram for a 33-H.P. Induction Motor.

Object of the Diagram.—To ascertain primarily the starting torque in terms of the full-load torque and also the relation between the various electrical quantities at all loads.

Rating of Motor.—33-B.H.P. 500 volts 750 revs. per minute synchronous speed, 725 revs. per minute full-load speed, 50-$\sim$ 3-phase squirrel-cage motor, with Δ-connected stator. Full-load line amperes $= 37$.

Tests Required.—1. Watts and volt-amperes at normal voltage and frequency with motor running without load.

2. Watts and volt-amperes with rotor at standstill, that is, with shaft clamped to prevent rotation.

3. Stator resistance (ohms per phase).

(1) Watts running light = 1,005 *
Volt-amperes running light = 500 × 10 † × 1·73
= 8,650
$\therefore$ Power factor at light load $= \frac{\text{true watts}}{\text{apparent watts}}$
$= \frac{1,005}{8,650}$
That is, $\cos \phi_1$ = 0·116
Angle whose cosine is 0·116 is 83° nearly.

(2) Watts at standstill = 3,480 ‡
Volt-amperes at standstill ... = 127 × 43 † × 1·73
= 9,450
$\therefore$ Power factor at standstill $= \frac{3,480}{9,450}$
That is, $\cos \phi_2$ = 0·36
And angle whose cosine is 0·36 is 68°.

(3) Resistance per phase = 0·775 ohms.

Construction of Diagram.—Lines O E and O A, Fig. 23, are drawn of indefinite length at right angles to represent the phase relationship between terminal pressure and stator flux (90°). The line O K is then set off at an angle of 83° with O E.

The no-load current per phase $= \frac{10}{\sqrt{3}}$ (Δ-connected stator).
= 6 amperes.

* By 2-wattmeter method. † Line amperes. ‡ Appendix II.

$\therefore$ Make O K = 6 amperes, taking a convenient scale, say 4 amperes per cm. Complete the no-load triangle of currents K F O by drawing K F vertical. Draw the horizontal line $b\,a$ through K. Set off the line O B_1 at an angle of $68° = \phi_2$ to represent in magnitude and phase the value of the standstill current per phase $= \frac{168}{\sqrt{3}}$, that is, 97 amperes.

$\therefore$ Make O $B_1 = 24{\cdot}25$ cm.

From the principle of the diagram it is known that the points B_1 and K must lie on the circumference of the current circle, and that its centre p must lie on the line O A. Therefore the circle A B_1 F can now be drawn, and this determines point A. Join B_1 A and draw Af perpendicular to B_1 A. This cuts the vertical line through p at the point f,

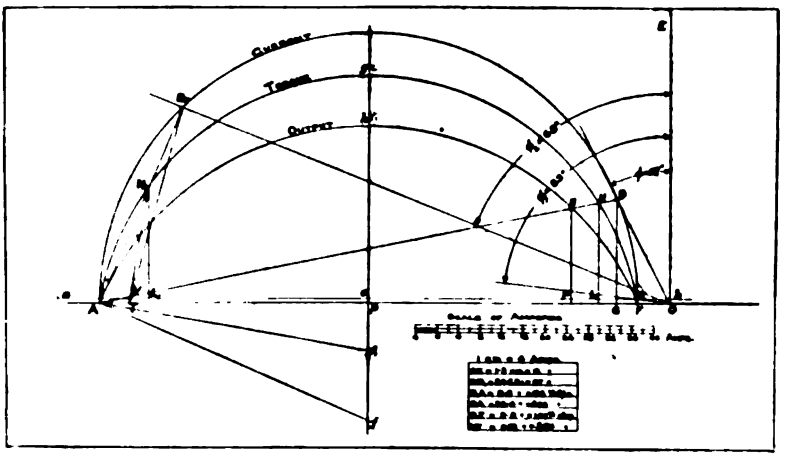


FIG. 23.

which is the centre of the output circle A N F drawn through the points A and F. Af is drawn perpendicular to A B_1 because A B_1 must be a tangent to the output circle, since the output of the stationary motor is zero under the conditions represented by the position of B_1 (that is when the motor is stationary). In order to find the "torque" circle A H F the scale to which B_1 A represents volts must be determined. Therefore measure the length of B_1 A and O A in the diagram, which are found to be 9·8 and 26·4 cm. respectively. The latter corresponds to a pressure per phase of 500 volts (Δ-connected stator).

$\therefore$ Value of vector $B_1 A = \frac{9{\cdot}8 \times 500}{26{\cdot}4} = 186$ volts.

The C^2R drop per phase of the stator for a current of 97 amperes $= 97 \times 0{\cdot}775$ (ohms) $= 75$ volts.

Hence to get the desired point H_1 on the torque circle, mark off along B_1 A from the point B_1 a piece B_1 H equal to $\frac{75 \times 9{\cdot}8}{186} = 3{\cdot}95$ cm.

This fixes the torque circle, which can now be drawn through points A, H, and F. To calibrate the diagram mark off the point B on the current circle by taking O as centre and a length O B = full-load amperes per phase to scale, that is $\frac{37}{\sqrt{3}}$

$$= 21{\cdot}5 \text{ amperes} = \frac{21{\cdot}5}{4} = 5{\cdot}37 \text{ cm.}$$

Then join B A cutting torque and output circles in points H and N respectively.

Then—

H L represents full-load torque,

and—

$H_1 L_1$ represents torque at "standstill,"

that is—

H L represents torque at starting.

Hence ratio $\frac{\text{starting torque}}{\text{full-load torque}} = \frac{H_1 L_1}{H L}$

By measurement—

$H_1 L_1$ is found to be 5·1 cm.

and—

H L „ „ „ 4·5 cm. $= \frac{5{\cdot}1}{4{\cdot}5}$

or torque at starting = 1·13 times full-load torque.

Angle E O B = ϕ is found to be 27° and cos ϕ = 0·89.
= full-load power factor, which is a maximum when O B is a tangent to semicircle A B F.

To get the slip line, drop a perpendicular from the point B_1 on the radius Af_1, thus getting the line $B_1 T$, which scales 9·2 cm. This is equal to a slip of 100 per cent., since the motor is not running. At the load corresponding to stator current O B, torque H L, and output N P, the slip is equal to the piece V T cut off on the slip line $B_1 T$, which scales 0·35 cm. Therefore full-load slip $= \frac{0{\cdot}35 \times 100}{9{\cdot}2} = 3{\cdot}8$ per cent.

To get the full-load watt input of the motor, measure the length of vector B G, which represents the energy component of stator current O B in the full-load triangle of currents O B G.

This length is found to be equivalent to 19 amperes.

Hence full-load watt input = (19 × 500 × 3)
= 28,500 watts.

At this load the losses are as follows :—

1. Light-load losses = 1,005 (from Test 1).

2. The stator copper loss for current O B = 21·5 amperes is given by the resistance per phase and component F B of stator current (not drawn on diagram).

F B is found to be equivalent to 19·6 amperes.
Stator copper loss = C^2R.
= (19·6 × 19·6 × 0·775 × 3).
= 891 watts.

In the diagram the line B H is proportional to this loss and scales 0·9 cm.

3. The rotor copper loss is proportional to the line H N in diagram, which scales 1·3 cm.

∴ Rotor copper loss (by proportion) = $\frac{891 \times 1{\cdot}3}{0{\cdot}9}$
= 1,291 watts.

Hence total losses at the load corresponding to point B (full load) = 1,005 + 891 + 1,291
= 3,187 watts.

Therefore watts output = 28,500 − 3,187
= 25,313 watts
= 34 B.H.P.

And efficiency... ... = $\frac{\text{output}}{\text{input}}$
= $\frac{25{,}313 \times 100}{28{,}500}$
= 89 per cent. (full load).

It will be seen from the above that the motor gives slightly more than its full-load output with a stator current of 21·5 amperes per phase; the line N P in the diagram therefore represents 34 B.H.P., and the value of all such lines as this, now that the value of one of them has been found, is definitely known.

Summary of Results—

Full-load power factor cos ϕ = 0·89.

Full-load efficiency ... = 89 per cent.

Apparent efficiency ... = power factor × efficiency.
= 89 × 89.
= 79 per cent.

Full-load slip = V T
= 3·8 per cent.

By taking O B of different lengths, *i.e.*, proportional to ½, ¼ and ¼ load currents per phase respectively, the corresponding values of power factor, efficiency, and slip can be obtained.

In the diagram (Fig. 23) the following characteristics of the motor are shown :—

1. The terminal pressure E is represented in phase by the vector O E.
2. The no-load magnetising current of the motor is given directly in magnitude and phase by the vector O F.
3. The stator current of the motor (C s) is given directly in magnitude and phase by the vector O B.
4. The power factor of the motor is given directly by the cosine of the angle ϕ : it is a maximum when O B is a tangent to the semicircle A B F.
5. The no-load current of the motor is given directly in magnitude and phase by the vector O K ; the no-load power factor is cos ϕ_1.

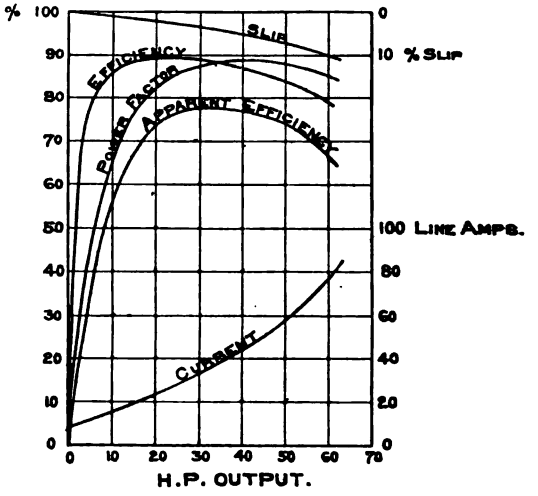


FIG. 24.

6. The watt component of the no-load current is given directly in magnitude and phase by the vector F K ; this fixes the line of the no-load losses $a\,b$, which is a parallel to O A through the point K.
7. The current in the rotor of the motor is directly proportional to the length of the vector F B (not drawn on diagram).
8. The input of the motor (C s × E × 1·73 × cos ϕ) is directly proportional to the length of the vector B G (E being constant).
9. The torque of the motor is directly proportional to the length of the vector H L ; the maximum torque the motor can exert before pulling up is directly proportional to the length of the vector $e\,g$.

10. The output of the motor (B.H.P.) is directly proportional to the length of the vector N P; the maximum output the motor can give without falling out of step is directly proportional to the length of the vector $e\,k$ (equivalent to 62 B.H.P.), that is, an overload capacity of 190 per cent.
11. The slip of the motor expressed as a percentage is directly proportional to the length of the vector V T; at starting it is equal to the length B, T = 100 per cent.
12. At starting the torque exerted by the motor is directly proportional to the length of the vector $H_1 L_1$; the starting current for this torque is equal to the length of the vector O B_1 = 97 amperes and the power factor at starting is given by cos ϕ_2 = 0·36.

Effect of Resistance in Rotor.—This increases the rotor copper loss, and as this is represented in the diagram by the piece A H_1, the effect of inserting resistance in the rotor is to cause the points H_1 and B_1 to take up positions higher up on the torque and current circles respectively. That is to say, the starting current is reduced and the starting torque is increased. The diagram as constructed is not strictly accurate, but is near enough for practical purposes. There is an error on the right side, which means that the motor is a little better in reality than is indicated by the foregoing investigation. Compare results obtained with those plotted in Fig. 24, which represent the makers' guarantees.

For a detailed study of the theory of the circle diagram, reference should be made to the Howard Lectures on "Polyphase Electric Working," by A. C. Eborall, pp. 70–80, also Hobart's "Electric Motors," p. 353.

APPENDIX II.

Note on Measurement of Watts and Current at "Standstill."

In taking these readings it is found that the results are dependent upon the position of the rotor with respect to the stator, there being two positions giving "maximum" and "minimum" currents respectively. This would be the case to a greater extent if the number of slots per pole on the stator were the same as the number per pole on the rotor. Where this happens there is a tendency for the motor to operate unduly as a mere transformer. For example, the apparatus shown in Fig. 25* would form an excellent 3-phase transformer without moving, the rotating field simply inducing synchronous 3-phase currents in the winding of the central part. In fact, this design with big teeth would not be self-starting. In practice, therefore, the stator and rotor have different numbers of slots, and in the case of "squirrel-cage" motors

* S. P. Thompson, "Polyphase Electric Currents," p. 186.

the two numbers have no common factor. Thus the motor under discussion has 72 slots in the stator, or 3 slots per pole and phase, while the rotor has 61 slots. Of course, where the rotor is furnished with a polar winding (slip-ring machine) it is impossible to prevent the

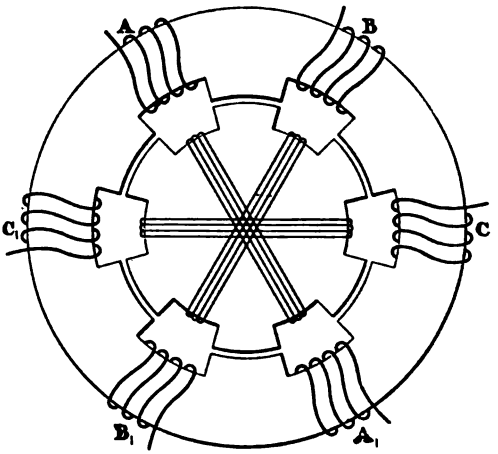


FIG. 25.

stator and rotor from having a common factor, because there must be not less than 3 slots per pole and phase. Hence the starting torque of slip-ring motors varies according to the position of the rotor.

DISCUSSION.

Mr. McMillan.

Mr. CAMPBELL MCMILLAN: I am not sure that I can throw very much light on the subject. I have been connected with the design and production of motors for some time now, and incidentally know a little about clutches which have been used in connection with them. On the subject of the adoption of a standard size of motor, I should like to say that the standardisation of characteristics in several cases would be as important as that of size. Mr. Stevenson has taken two classes of motors for the engineer engaged in the application of induction motors to choose from—those with short-circuit or squirrel-cage rotors and those with slip-ring or wound rotors, but I think he might add a third class—those with internal resistance. They do not require any slip rings, and in many cases they are much simpler and are recommended for certain sizes up to about 50 H.P. It is interesting to note that in the comparison of prices these vary very much according to the copper market, because the chief gain in the squirrel-cage rotor is the relatively small amount of copper in the design. The same remark applies to the motors compared on page 677, where the difference in weight is accounted for by the difference in the copper. As to the

mechanical qualities of the squirrel-cage rotor, there are some drawbacks, and in a standard construction the variety of mechanical details to avoid these is very great. According to the methods of design and calculation which Mr. Stevenson has followed, it may be necessary and advisable to take some typical tests such as he has taken, but I know that great quantities of electrical motors are turned out on calculations which obtain all these results in advance very accurately. In connection with the very neat method of starting patented by Mr. Meyer, simplicity of operation is sometimes obtained at the expense of limiting the freedom of the designer, and any one who has tested the difficulties of fitting windings into motors according to desired characteristics will relinquish with the greatest reluctance the freedom to change over from the delta-connection to Y as the requirements demand. I admit that it is only in certain conditions when the speeds and voltages are within certain limits that they are under such stress, but these are quite important cases also. The possibility of using the same starting device for several different motors may simplify matters, but it is always necessary to have similar motors in order to be able to do that. At the beginning of the paper we are promised that, even if starting devices are included, the squirrel-cage motor comes out still cheaper in sizes up to and including 50 H.P., because, as is shown later, the starting-gear for that type is much simpler and less expensive than that required for the motor with wound rotor. I think it would be fairer to say that they are "sometimes" much simpler, because the occasions on which the same switch can be used for a number of motors are rather limited. There is certainly another objection to the compensator on account of its excessive cost relative to the motor. The device referred to at the foot of page 686, I think, is worthy of more attention. It may be found to alter the problem very considerably. I am not sure whether much information is available on the subject, and it would be very interesting if any one can give us any light as to the practical design of these motors. They claim to have all the characteristics of a slip-ring motor including short-circuiting device, and absolutely no trouble with slip rings. In connection with clutches I have not had much experience. I know no clutch larger than one of 700 H.P., and I have not seen it in actual working, but only under testing conditions, and in considering clutches one must analyse their functions a little more closely. A clutch has a double function to fulfil, and although this coil clutch may fulfil one, I am not sure whether it will the other. A clutch must be to a certain extent a brake, and it must be an absorber of energy for a certain time. Even when carefully put on a shaft it will only absorb the energy to the extent to which it can dissipate the heat. These are very important conditions. To find out whether such a clutch is suitable for work one must not only know the torque, but the inertia effect on the various portions of the machinery. If there is any defect in the machinery the time required to obtain the full speed may mean a great amount of heat generated in the coil, and provision must be made for the dissipation of that heat. I think that has been the chief trouble in most clutches—

Mr. McMillan.

Mr. McMillan. not that they fail to grip, but that they do not dissipate the heat in a proper manner. Perhaps it may complete the information given on page 696 if Mr. Stevenson can tell us what percentage of the power has been installed as squirrel-cage motors as well as the number of motors.

Mr. Nicholson. Mr. JOHN S. NICHOLSON: At the foot of page 678 Mr. Stevenson, in speaking of the squirrel-cage machine, states that the absence of moving contacts is a conspicuous advantage, which makes it absolutely sparkless, and therefore specially suited for operation in mines or mills where dangers from explosive mixtures or gases exist, and a few pages further on he says that machines up to 20 H.P. may be used with an air-break switch, and above that size it is good practice to use an oil-break switch; but I should imagine that where squirrel-cage machines are being made with an overthrow switch it would not be so sparkless as he supposes. On page 683 he speaks of the probable saving by the use of roller bearings as opposed to the ordinary cylindrical bearings, which may amount to 10 to 25 per cent. of the power. That corroborates one or two experiments which I have made with a 10-H.P. induction motor, where I found that the "no load" losses with the ordinary bearing were so much, and when the ordinary bearings were exchanged for roller bearings the "no load" losses diminished by fully 10 per cent., so that in ordinary cases, with a long line of shafting, the saving of power would be a great deal higher, perhaps 25 per cent. or more, since in the ordinary induction motor the windage torque may be a considerable fraction of the total retarding torque on "no load." On page 692 Mr. Stevenson states that the starting current is independent of the load on the motor. That is quite true, and in the following sentence he speaks of the acceleration when the load is small. Of course, if the load is very heavy the machine may take a long time to start up, and one does not want to have a starting current for more than one or two seconds, or even a fraction of a second. It may be anything up to 6 times the ordinary and full-load current, so that the starting current is not quite independent of the load on the motor. The introduction of roller bearings will reduce the time taken to start by a very appreciable amount. On page 693, in speaking of a 33-H.P. motor, Mr. Stevenson says that, by increasing the rotor resistance by 66 per cent. the starting current will be reduced by 3 per cent., and the starting torque will be increased by 1¾ times full-load torque. He then says: "The increase in the resistance of the rotor naturally causes greater C^2R losses, so that this means a lower efficiency, but the difference is such as in many cases to be well worth the advantage gained in respect to the starting qualities of the machine. In the case under discussion, the efficiency would be reduced by 2 per cent." I think myself it would probably be reduced by at least 3 per cent. It does not seem a big difference, but it is always 1 per cent. more. That is due to the high current density in the rotor. Mr. M'Millan has spoken about copper, and the copper losses in the motor at full load are greater than the iron losses, and thus bear a higher percentage of the total losses. In the case of a motor tested recently, there was some difficulty in

starting as an ordinary squirrel-cage machine, and the rotor winding was altered slightly, and the efficiency fell about 4 or 5 per cent. at full load below its previous value before the rotor was altered. If such a motor is supposed to run at full load, that 4 per cent. loss means a big thing. Mr. Stevenson states that the reduction in the apparent efficiency, which is an important point, will be slightly less than 3 per cent., and then he states that the machines should not be made too large. That means that each machine would be running at as nearly as possible full load, and the increase in the rotor resistance then makes a great difference in the efficiency. I am rather sorry that Mr. Stevenson does not say much about the circle diagram shown in Fig. 23. The assumptions made are considerable. After obtaining the current circle, the torque and the output circles are deduced; we then get the starting torque from the line H_1 to L_1 on the figure. We made some tests on the starting torque of an induction motor, and found by experiment that it was nearly 2 times the ordinary full-load torque, and taking it from the circle diagram, we found that it was only 1·1 times. That is a very great difference, so, after all, perhaps the circle diagram is not very accurate in every respect. Mr. Nicholson.

Mr. W. B. HIRD: I propose to confine my remarks to one point on which Mr. Stevenson lays great stress—the superiority, for most purposes, of the squirrel-cage motor over the slip-ring motor. Mr. Hird.

The advantages of the squirrel-cage motor are very evident from the manufacturer's point of view, it is an easier and cheaper machine to build, and is less likely to give trouble of any kind. From the consumer's point of view also, the robust construction of the rotor and the fact that the machine will run with less attention owing to the absence of moving contacts, are strong recommendations. It would appear, however, from the table given by Mr. Stevenson, that many of the supply companies entirely fail to realise the advantages of the squirrel-cage motor. The squirrel-cage motor has a somewhat better power factor than the corresponding slip-ring motor, and this is a point in favour of the suppliers; but the chief consideration for them is that, if the squirrel-cage motor is really the simplest and easiest for the consumer to handle, they certainly keep away business by imposing undue restrictions to its employment. There is, I think, no doubt that some of the companies do impose very unreasonable restrictions to the use of squirrel-cage motors, simply from fear of the large starting current. Mr. Stevenson has laid emphasis on all these points, but I do not agree with him as to the proposed remedy. I do not think that there is any hope of getting consumers to adopt to any large extent such a piece of apparatus as a friction clutch. I have had no experience with friction clutches for high powers, but from all I have heard about them, I think I have perhaps been lucky in not having this experience, and there is no doubt that friction clutches are looked upon with great disfavour by most people.

There is a way of starting a squirrel-cage induction motor which is

Mr. Hird. practically equivalent to the use of a clutch, and which does away with all the disadvantages of mechanical clutches. A few weeks ago in this very room, Mr. Henry A. Mavor described an induction motor which he has devised, and which he calls a "spinner motor." In this motor the member carrying the primary winding and generally known as the stator, is mounted on bearings so as to be capable of rotation, and is then called the "spinner." The rotor being mechanically coupled to the load, and the spinner free to rotate when the current is switched on, the spinner will accelerate to synchronous speed; a brake is then gradually applied, and the stator brought to rest. During this time the rotor accelerates so as to keep the relative speed between primary and secondary the same. The method is under perfect control, and by proper handling of the brakes, the current, whilst the load is being accelerated, can be kept down as nearly as desired to the load current. The whole thing is self-contained, there is no need for the purchaser to alter any of his existing arrangements, or to instal additional apparatus, and the extra cost of the motor is not greater than the cost of any friction clutch on the market.

It seems possible that on the development of such a machine will be found the solution of the difficulty of starting squirrel-cage motors under load, and that it may lead to the adoption of squirrel-cage motors in many places where they would otherwise not be possible, and where the mere mention of a friction clutch might frighten the prospective customer from adopting any induction motor whatever.

Mr. Belsey. Mr. W. J. BELSEY: I should like to emphasise the importance of judging an induction motor by the apparent efficiency and not so much by the power factor of the efficiency. In the first place, the power factor is an extremely difficult thing to measure with any degree of accuracy, whereas the efficiency can be determined pretty accurately.

Mr. Craig. Mr. J. HALLY CRAIG: With many of Mr. Stevenson's views I am disposed to agree, but I think that he has been a little too severe on the slip-ring rotor. Undoubtedly the squirrel-cage rotor has many advantages that appeal to the user and to the purchaser, but the slip-ring rotor has also many good qualities. The device to which Mr. Stevenson has referred in rather a disparaging manner, if properly constructed, is perfectly reliable.

Mr. Tittensor. Mr. W. H. TITTENSOR: People are beginning to realise that shafting costs money to run, though few mill owners would believe that they are wasting 50 or 60 per cent. of their power. There are many cases where small manufacturers cannot afford to go in for separate motors, and they want to put in one motor for the shafting; but if they really wish to get the best results they should go in for separate motors. With regard to clutches, I am glad to say I have not had much experience of them in a large size, as I know a number of people who have, and when asked for their experience they have replied that they would rather not give it.

Mr. Stevenson. Mr. STEVENSON (*in reply*): I have to thank Mr. M'Millan for the very interesting and extensive criticism of the paper that he has given.

Mr. Stevenson.

With regard to the curves showing the comparative prices, I quite agree that these prices depend upon the market value of copper; but I do not think that this is a very important point, because the price of a squirrel-cage will always be much less than that of a slip-ring machine, quite irrespective of market fluctuations. The curves given are well on the safe side, as the difference in price between the two types is given as 5 per cent. only. As a matter of fact, I find that some manufacturers can supply squirrel-cage machines at prices in the nature of 20 to 30 per cent. less than the corresponding sizes with wound rotor.

With regard to the predetermination of the results mentioned by Mr. M'Millan, I do not think this would appeal very much to the power user, however valuable it might be from the designer's standpoint. I feel sure that a good part of the design of an induction motor is due more to intelligent guessing, coupled with the use of previous test results. For my purpose it was essential that I should be able to go upon first-hand knowledge, and therefore I naturally preferred to rely on the actual test figures. I think that most of the members will agree that calculated results and test results are two quite different things.

As regards Hunt's method of starting, I am afraid that this arrangement could only be applied successfully on large motors, as it appears to me that there is insufficient space in the smaller sizes to accommodate the very special windings. Mr. M'Millan raised an important point when he referred to the percentage of the power installed in squirrel-cage machines in the installation referred to in the paper. The percentage aggregate power of the squirrel-cage motors is 75. The largest slip-ring motor is of 40 H.P. and the largest squirrel-cage 33 H.P. In laying out an induction motor plant, it is good practice so to arrange matters that the total capacity of squirrel-cage motors on any one generating plant shall not exceed a total in B.H.P. of about one-half the generator capacity in kilowatts. Furthermore, no single squirrel-cage motor should be of greater B.H.P. capacity than one-tenth the generator capacity in kilowatts. For instance, where power is supplied by a 500-k.w. set, no single squirrel-cage motor should be greater than 50 B.H.P., and the total capacity of squirrel-cage motors on this set should not be more than 250 B.H.P. These figures are based on the assumption that it is desired to start up the motors on load. Of course, if clutches are used, it would be possible to instal larger squirrel-cage machines.

With regard to the internal resistance method mentioned by Mr. M'Millan, I am altogether against that. It may be all right in America, but the climatic conditions over here do not permit of its successful adoption. In this connection I might mention that Mr. Meyer devised an interesting method for starting squirrel-cage machines, which consisted in furnishing the rotor with two windings, one of iron and the other of copper, and arranging to cut out the former after the machine had run up to speed. Several machines were made and tested under

Mr. Stevenson.

actual working conditions, but it was found that the iron wires got rusted up and caused endless trouble. Of course, such a motor might be entirely satisfactory in a dry climate. An ingenious arrangement has recently been introduced by Steinmetz,* who utilises the electrical properties of magnetite. This material has a high resistance at ordinary temperatures, but becomes a good conductor at high temperatures. The rotor bars are in electrical contact with the short-circuiting rings only through magnetite washers, the fastening bolt being insulated both from the washer and the ring. The resistance of the rotor circuits is thus large at the start, owing to the resistance of the washers, but when the washers get hot their resistance is negligible. When the rotor stops, the washers cool rapidly, being in contact with a metal ring, and so the motor can safely be restarted almost immediately.

In reply to Mr. Nicholson, what I have said as to the air-break switches is quite correct, but of course in the case of fiery mines such a switch would never be used. The type shown in Fig. 8 is specially suited for such a purpose. The switch proper is enclosed in a cast-iron box filled with oil. With regard to the circle diagram, I quite agree that it is not strictly accurate, if it is dissected bit by bit, but taken all over, the errors seem to cancel each other out, and I maintain that, from a practical man's point of view, it is a most useful diagram, and we can learn a great deal about the performance of the motor by its use. It is not really so difficult to construct as it appears to be, for once one diagram is plotted out the rest is easy. Roughly speaking, it is the electrical man's steam indicator diagram. I should have liked to have been able to devote more time to the diagram when reading the paper, but it is such a large subject that it was quite impossible to do more than glance at it, so I preferred simply to detail the various steps as clearly as possible, and confine the whole thing to the appendix. Adequately to deal with it would require a separate paper. I am interested to learn that Mr. Nicholson has obtained results in regard to the use of roller bearings which confirm the figures given in the paper.

As regards the loss in efficiency referred to by Mr. Nicholson, I am not in a position to go into this. He may be correct in stating that the difference is 3 per cent. as against my 2 per cent. I do not know, but I do not think that a matter of 1 per cent. is of any great importance in the majority of industrial cases that one has to deal with, and I should be quite prepared to drop this amount if I could thereby get a machine having the desired characteristics.

With regard to Mr. Hird's remarks, I think he has furnished me with an excellent example in proof of the statement at the foot of page 696 in the paper. Why should we go out of the way in solving a simple mechanical problem, by adopting a much more complicated electrical method? I believe I am correct in stating that the idea referred to by

* "Russell's Alternating-current Theory," vol. 2, p. 382.

Mr. Hird is not by any means new, it having been put forward by De Lignieres * in 1903. The fact that it has made so little progress since that time is, I think, convincing proof that the method is incapable of being made a commercial success. Mr. Stevenson.

I do not think Mr. Hird can be correct in his statement that the cost of such an arrangement comes out at no more than a squirrel-cage machine plus a friction clutch. Besides, the friction clutch is only one out of many other possible mechanical devices by the use of which a squirrel-cage machine can be adopted, and one of the objects of the paper was to draw attention to these methods.

Then, again, the arrangement of Mr. Mavor's motor means very special bearings, and I think this is really the crux of the whole matter, and the point where trouble would begin.

Turning now to a consideration of the remarks that have been made on the friction clutch, there is one fact with which I have been struck, namely, that not a single speaker had any first-hand information or experience with clutches of the sizes mentioned. I am therefore forced to the conclusion that what has been said in this connection does not carry much weight, and I maintain that a squirrel-cage motor, together with a well-designed friction clutch, is a more efficient, cheaper, simpler, more robust, more reliable, and altogether a much sounder bit of engineering than an equivalent slip-ring machine. Of course I quite recognise that the former has its limitations, and there are cases where it should give place to the machine with wound rotor, but, generally speaking, these are fewer than might be supposed. Experience in the use of coil clutches has shown that the wear is practically negligible, several drives being in use for rolling mill work for at least seven years. What actually happens is that the metal becomes fatigued rather than worn out, which results in the head of the coil breaking off. Of course the renewal of this part is a simple matter.

Mr. Belsey mentioned the difficulties attendant on the separate measurements of power factor and efficiency, and I quite agree with him in this. It would certainly be better from the manufacturer's point of view if guarantees were given on the apparent efficiency instead, since test results sometimes give power factors well over the guarantee and efficiencies under the guarantee.

Mr. Craig has referred to a special method of starting large motors, and it is very interesting to know that 1,000-H.P. squirrel-cage machines can be started up in such a simple manner. As regards slip-ring motors, Mr. Craig's experience must have been more favourable than mine. I am quite sure that there will be just as much trouble with a 3-phase slip-ring as with a continuous-current motor when it is put down a coal-pit and subjected to the rough usage it is bound to get. In view of the autocratic attitude adopted by some local authorities towards their consumers it is

* A. Hay: "Alternating Currents," p. 217.

Mr. Stevenson.

refreshing to hear of a case where current is being supplied without any of the restrictions usually imposed in regard to the size of motors, etc.

Mr. Tittensor has corroborated my views as regards shafting losses.

With respect to the size of the motor it may be worth while pointing out that the Y-delta arrangement can be used very nicely where it is necessary to instal a motor somewhat too large for its work in the first instance. To begin with, the motor would be run normally on Y-connection, but after the load had increased to a sufficient extent the delta-connection would be used, and by this means higher efficiencies and power factors would be obtained.

The Chairman moved a hearty vote of thanks to Mr. Stevenson for his valuable paper.

THE DESIGN AND USE OF TELEPHONE AND TELEGRAPH CABLES.

By F. TREMAIN, Member.

(*Paper received from the* NEWCASTLE LOCAL SECTION, *February 26, and read at Newcastle, April 6, 1908.*)

Recent designs of telephone and telegraph cables have been almost entirely limited to the paper-insulated lead-sheathed variety; for aerial cables as well as underground cables are now of this type, and other types of aerial cable and submarine cables have not to any large extent been altered in character for many years. It is, therefore, proposed to confine attention in this paper to the type almost universally employed for telephone and telegraph circuits.

The cost is governed in the case of large multiple cables by the quantity of copper required, although in small cables lead may become the governing factor.

For telegraph purposes pure and simple a single wire insulated with paper and surrounded by a screening tape of copper is in general use, although in cables which may be used interchangeably for telephone or telegraph purposes pairs of wires are used for both purposes as will be explained later.

In each case a copper wire, which varies in diameter from 25 mils for local purposes to 113 mils for trunk purposes, is insulated by means of paper carefully selected and of long fibre. The paper is generally applied longitudinally in a suitable covering machine which is sometimes arranged to supplement the longitudinal wrapping by a helical covering, both being applied without much tension, so as to leave as much air-space as possible between the wire and the individual wrappings of paper. In lieu of the helical wrapping of paper a whipping of thread is often used. The paper used varies in thickness from 3 or 4 mils to as much as 10 mils in the case of very heavy conductors.

In the case of screened conductors the screening copper tape is about 3 mils in thickness and about $\frac{1}{4}$ to $\frac{1}{2}$-in. in width applied helically with a slight overlap, its object being to screen the conductor from the inductive effect of neighbouring conductors traversed by telegraphic impulses.

The screened conductors vary in diameter from 50 mils, weighing 40 lbs. per mile to 113 mils weighing 200 lbs. per mile, and in the smaller sizes the screening tape, although rolled as thin as possible, is practically of the same weight as the conductor itself. Care is taken in stranding the wires into a cable that the screening tape is in contact

with the lead sheathing and therefore earthed. The electrostatic capacity of such a conductor measured to earth is 0·097 to 0·133 microfarads per mile. The calculated dimensions for various capacities, etc., are given in Table I.

When the conductors are not screened, two wires insulated in the manner described are twisted together in a twinning machine with a definite length of lay varying in Post Office cables from 4 in. to 13 in., and each length of lay is indicated by the use of a coloured wrapping, which insures that no two pairs of the same lay are adjacent when the pairs are stranded to make a cable or cable core.

The efficiency of such a pair of conductors depends on their conductivity, the electrostatic capacity from wire to wire, and the inductance of the loop formed by the pair of wires.

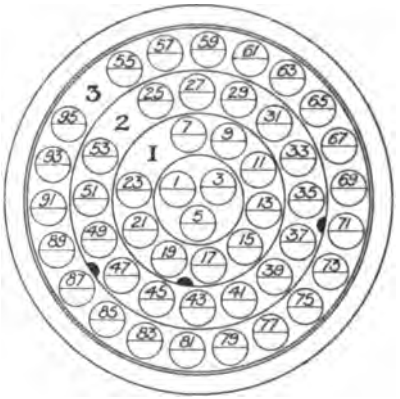


FIG. 1.

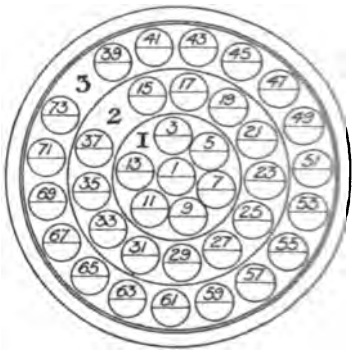


FIG. 2.

Stranding and Numbering.

Cables with 6 wires and upwards. Cables with 14 wires and upwards.

The electrostatic capacity varies from 0·04 to 0·07 microfarads per mile and the self-induction from 0·9 to 1·4 millihenrys per mile.

A rough empirical rule for determining the space requisite for any desired wire-to-wire capacity, with the class of paper and method of covering usually employed, is that if the diameter of the completed pair of wires is three times that of one of the conductors, the wire-to-wire capacity measures about 0·07. If the ratio is four to one, the capacity measures 0·055 or thereabouts, whilst if the diameter of the pair of wires is increased to five times that of one of the conductors forming it, the capacity falls to a little over 0·04 microfarads per mile.

It is not impossible, therefore, to obtain in a cable a more efficient loop with conductors weighing 100 lbs. to the mile than with 150-lb. conductors; for if the latter are made to have a capacity of, say, 0·07 microfarads per mile and the former 0·045 microfarads, on the basis of K R alone the 100-lb. loop would be more efficient, and in addition it

TABLE I.

Air-space Paper-core Cables.

Screened Conductors.

Calculated Dimensions for various Capacities and Values of K.R. per Mile.

Type of Conductor.	For Capacity of 0·15 Microfarads per Mile.		For Capacity of 0·12 Microfarads per Mile.		For Capacity of 0·11 Microfarads per Mile.		For Capacity of 0·10 Microfarads per Mile.		For Capacity of 0·09 Microfarads per Mile.		For Capacity of 0·08 Microfarads per Mile.	
	Diameter of Core.	K R. One Mile.	Diameter of Core.	K R. One Mile.	Diameter of Core.	K R. One Mile.	Diameter of Core.	K R. One Mile.	Diameter of Core.	K R. One Mile.	Diameter of Core.	K R. One Mile.
Lbs. per Mile.	Mils.		Mils.		Mils.		Mils.		Mils.		Mils.	
40	160	3·2940	214	2·6350	244	2·4150	286	2·1960	348	1·9770	443	1·7570
70	211	1·8810	283	1·5050	323	1·3800	378	1·2540	459	1·1290	585	1·0030
100	253	1·3180	338	1·0540	386	0·9663	453	0·8784	549	0·7906	700	0·7029
150	310	0·8784	416	0·7029	474	0·6442	556	0·5856	674	0·5271	860	0·4685

would have a higher inductance, say 1·2 millihenrys per mile as against as little as 0·9 millihenrys. It follows that in cable designing, paper and air being cheaper than copper, great advantages follow from a well-considered design.

The great importance of obtaining a low electrostatic capacity in a telephone loop will be seen from the illustrations of distortion given in Sir John Gavey's Presidential Address * in 1905, and in Cohen and Shepherd's paper on telephone transmission measurements.† The table of equivalent circuits in the former paper, some the results of experiments and others based on formulæ, are interesting from this point of view.

There is also room for much ingenuity in the assembly of the pairs of wires to form a cable—more so than in the case of screened conductors which usually form the outer layer or layers of the cable, and are not often stranded to form pairs or other cores.



FIG. 3.—Stranding and Numbering.
Cables with 8 wires and upwards.

The original method, and one still much in vogue, is to strand the alternate pairs up layer by layer in a stranding machine, each alternate layer forming a left-handed and right-handed spiral. The number of pairs thus stranded varies from seven pairs in a small distribution cable to as many as 606 pairs in the largest main telephone cable. In these very large multiple cables for local service the smallest wires quoted above are used. This method of laying up cables in regular layers is quite straightforward and calls for no comment, but the central wire or wires and the character of the successive layers in these "simple twin" cables are indicated in Figs. 1, 2, and 3.

Two other methods of stranding the pairs are in general use :—

(*a*) The quadruple pair type.
(*b*) The multiple twin type.

These it will be interesting to describe in some detail; but before doing so it will, perhaps, be well to discuss the varied requirements which multiple subterranean cables are required to meet, which may be classified as follows :—

(*a*) Trunk line telephone cables.
(*b*) Junction telephone cables.
(*c*) Main telephone cables wholly allocated to subscribers' lines from an exchange centre.
(*d*) Composite cables providing for any two or three of the above services.
(*e*) Composite cables primarily intended for telephonic purposes, but also containing telegraphic wires.

* *Journal, Institution of Electrical Engineers*, vol. 36. p. 4, 1906.
† Ibid., vol. 39, p. 503, 1907.

The chief defects in the original type which these special cables were designed to avoid are :—

(*a*) Their inefficiency for anything but short distance communications.
(*b*) Their costliness in the provision of spare wires.
(*c*) The waste involved in the uncertainty as to the ultimate requirements at the points selected for distribution.

They are also unsuitable for superimposed circuits, in considerable use on aerial lines to which these are often connected, and they generally provide for the short-distance subscriber's circuit the same weight of conductor as for circuits of greater length.

As regards the last point it may be noticed that an ideal conductor for subscriber's circuits would be one that tapered gradually, from the longest distance served on a route to the shortest from the exchange, the wire-to-wire capacity per mile being also reduced as the length increased. This would allow of any pair of conductors being appropriated for a new subscriber, wherever he may be, ensuring equality of treatment for all subscribers within the telephone area. This equality is very desirable if the long-distance trunk service is to be available for all users of the telephone without regard to their situation relative to the trunk centre. If this be admitted, the longest trunk circuit provided will determine the efficiency requisite in a telephone area.

A similar line of reasoning is applicable to multiple trunk line cables, in which it is rarely possible to allocate, in the first instance, the whole of the wires for suitable trunk lines. Now it is clearly impossible to secure this ideal equality of treatment in a telephonic network, nor is it possible, when multiple cables are used for trunk circuits, to provide equal efficiency for lines of varying length unless the ultimate appropriation of all the wires can be foreseen. On an aerial line, on the contrary, conductors of suitable gauge can be added from time to time.

It is to meet these difficulties that composite cables, containing different gauges of wire, have been manufactured, but their utility is limited, and they have the disadvantage that a larger number of conductors of fixed gauge have to be provided for future use. This condition naturally suggests the grouping of wires in a cable to form conductors of larger cross-section, an arrangement which cannot be carried out with any electrical advantage in the case of cables in which the pairs of wires are arranged in layers in the usual manner.

In the two types above mentioned this difficulty is met by stranding pairs in such a way that, (*a*) in addition to the individual pairs being available to form a twisted looped circuit, the wires of two or more pairs may be bunched to provide double conductivity without materially increased capacity ; (*b*) by the use of transformers the unit loops can be utilised for a circuit at the same time as those of double conductivity. In quadruple pair cable four pairs of wire are stranded around a centre

of yarn, to form quadruple pair cores, and where the conductors are large enough, weighing 100 lbs. or more per mile, these four pairs are wormed with four pairs of smaller gauge, weighing 10 lbs. or more per mile, forming an 8-pair core. These cores are then laid up into a cable of any desired number of pairs.

Quadruple pair cores, being large, allow of the helical interstices formed in each layer being utilised for smaller pairs of wires, as may be found necessary.

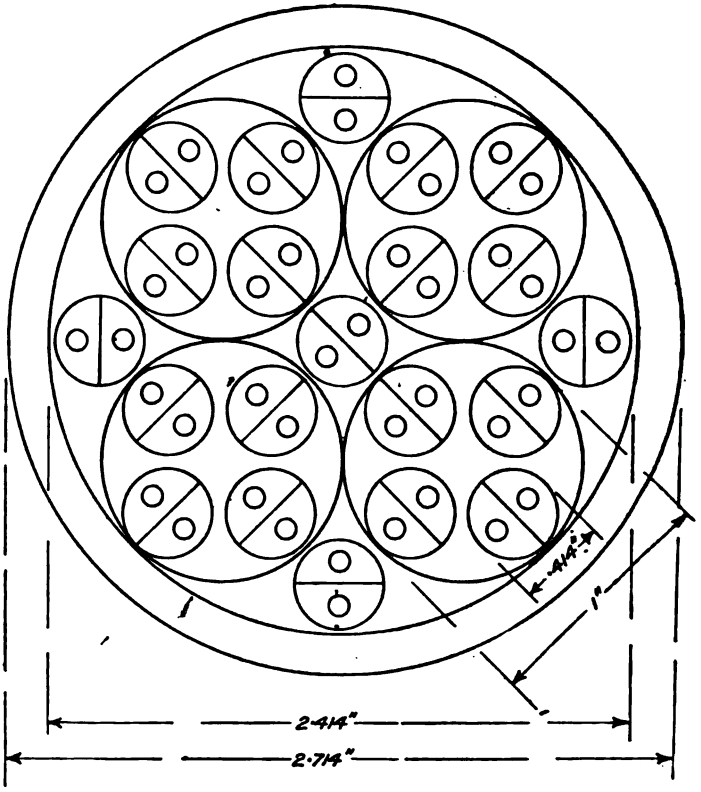


FIG. 4.

The quadruple pair formation admits of two diagonal pairs being each bunched to form conductors of double conductivity, the two pairs being used for a metallic telephone circuit. The stranding of the four pairs around a common centre ensures that these loops of double conductivity shall be non-inductive to any similar loops in the same cable. The mutual capacity between these conductors of double conductivity is not materially greater, and may be made actually less (see Table IV.),

than that obtained between the conductors of the unit pairs of which they are made up. An electrical advantage is thus secured, and speech can as a result be carried on over a much greater distance. In the same way all the four wires forming a part of two neighbouring pairs can be grouped together to form a conductor of fourfold conductivity and can be associated with the other four wires, similarly grouped to

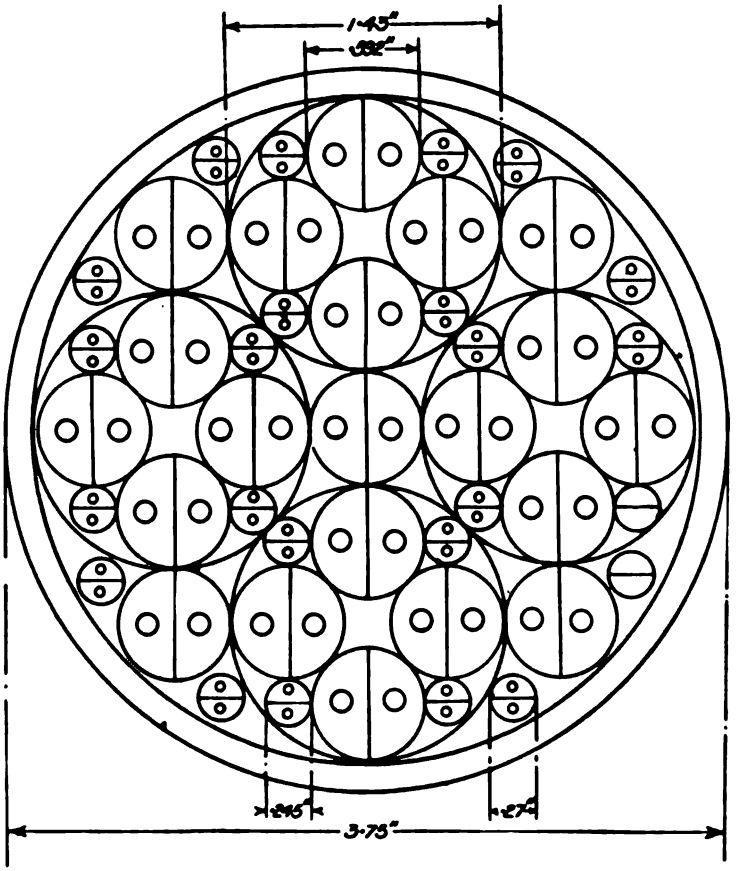


FIG. 5.

form a telephone loop, this loop of fourfold conductivity being non-inductive to other loops in the cable. The capacity of such a loop is necessarily higher than that formed of diagonal pairs, but the arrangement would sometimes prove advantageous. The worming pairs can also be grouped in the same way, and the mutual capacity results obtained with this combination are interesting.

All the remarks as to bunching conductors apply to superimposed circuits, for one of these loops is obtained, in such a system, by bunching the initial conductors through one winding of a transformer. The general result obtained will be best illustrated by reference to a diagram of a 42-wire cable (Fig. 4), excellent electrical tests having been obtained with a cable of this type. It will be seen that the cable is formed of four quadruple pairs laid around a central pair of the same size and wormed with four pairs of equal weight, this being the correct geometrical formation. The wires of the pairs forming each core are laid up with a different lay, to ensure immunity from cross-talk and to

TABLE II.

Air-space Paper-core Cables.

42-wire 100-lb. Quadruple Pair Core. Tests on Completion.

Length, 11 Miles.

Circuit Tested for Electrostatic Capacity. Weight of Conductor per Mile.	Microfarads per Mile of Loop.			Resistance Ohms per Mile of Conductor.
	Maximum.	Mean.	Minimum.	
Wire to wire of pairs, 100 lbs.	0·0446	0·0416	0·0391	8·62
Between diagonal of quadruple pairs, cores 200 lbs.	0·0502	0·0487	0·0469	4·31
Between diagonal worming pairs (across cable), 200 lbs.	—	0·0453	0·0400	4·31
Between neighbouring double pairs of quadruple cores, 400 lbs. ...	—	0·0963	—	2·16
Between diagonal quadruple cores, each 800lbs.	—	0·0905	—	1·08

ensure the same result when the pairs are bunched as described; the four quadruple cores have also different lengths of lay. The quadruple cores in this cable are about 1 in. in diameter, and the complete cable over the lead sheathing has a diameter of 2·71 in., which is nearly the maximum size permissible for a 3-in. pipe. The electrical results given by an 11-mile length of such a cable are shown in Table II. This may be regarded as typical of trunk-line cables, but for long-distance transmission it would be desirable to provide 200-lb. conductors and a cable 3¾ in. in diameter drawn through 4-in. pipes (Fig. 5). The electrical results obtained on a 2½-mile length of this

cable are given in Table III., and are very similar to those obtained in the smaller cable. With such a cable telephonic speech between London and Manchester would be practicable. The cost, including pipe-work, cabling, jointing, and equipment, would be high—exceeding, probably, £300,000—but by the addition of 100-lb. worming pairs as shown in Fig. 5 and the sample on view, 24 circuits would be provided, adequate for intermediate distances—a total of 48 metallic circuits. This number could be increased to about 60 by the superimposing scheme illustrated diagrammatically in Fig. 6. No doubt it would be

TABLE III.

AIR-SPACE PAPER-CORE CABLES.

Quadruple Pairs with Worming.

Diameter, 3¾ in. 42–200-lb. Conductors.

48–100-lb. Conductors.

Circuit Tested for Electrostatic Capacity. Effective Weight of Conductors per Mile.	Mean Capacity. Microfarads per Mile of Loop.	Resistance Ohms per Mile of Conductor.
Wire to wire of 100-lb. pairs	0·0607	8·62
Wire to wire of 200-lb. pairs	0·0456	4·31
Diagonal worming pairs bunched to form 400-lb. loop across the cable	0·0400	2·16
Between diagonal bunched pairs of quadruple cores, 400 lbs. ...	0·0500	2·16
Diagonal quadruple cores bunched (100-lb. conductors) to form 800-lb. loop	0·1200	1·08
Diagonal quadruple cores bunched (200-lb. conductors) to form 1,600-lb. loop	0·1100	0·54
Diagonal quadruple cores bunched (200- and 100-lb. conductors) to form 2,400-lb. loop	0·1600	0·36

desirable in such a case to provide for loading the cable with inductance coils at every 2 or 2½ miles. A small conductor quadruple pair cable is illustrated in Fig. 7.

In the multiple twin type the facility for increasing the conductivity without abnormally increasing the capacity of the heavier loop is obtained by a system of successive twinning. Two pairs of wire having been made in the way already described, these are twisted together to form a double pair. These two pairs serve the same

purpose as the diagonal pairs of the quadruple core described above. A similar double pair having been prepared, the two double pairs are in turn twisted together to form a pair of fourfold conductivity (see Fig. 11). Eight-wire cores formed in this way are laid up into a cable, and although the fourfold pairs cannot be wormed with smaller conductors as can the quadruple cores, layers of them can be wormed with small groups of pairs or by single pairs as can layers of quadruple

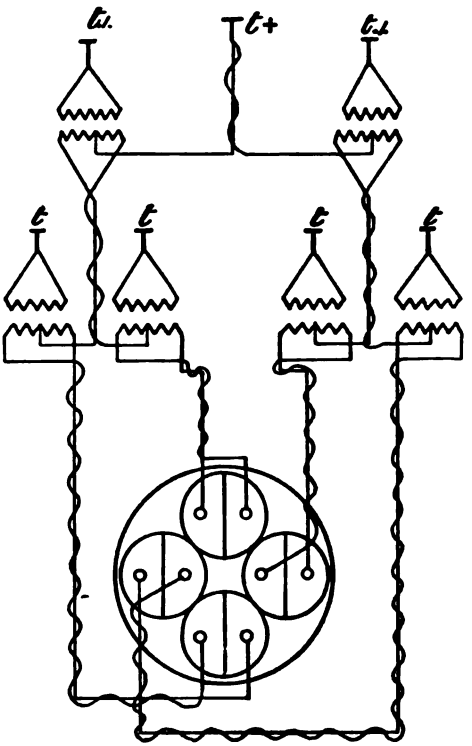
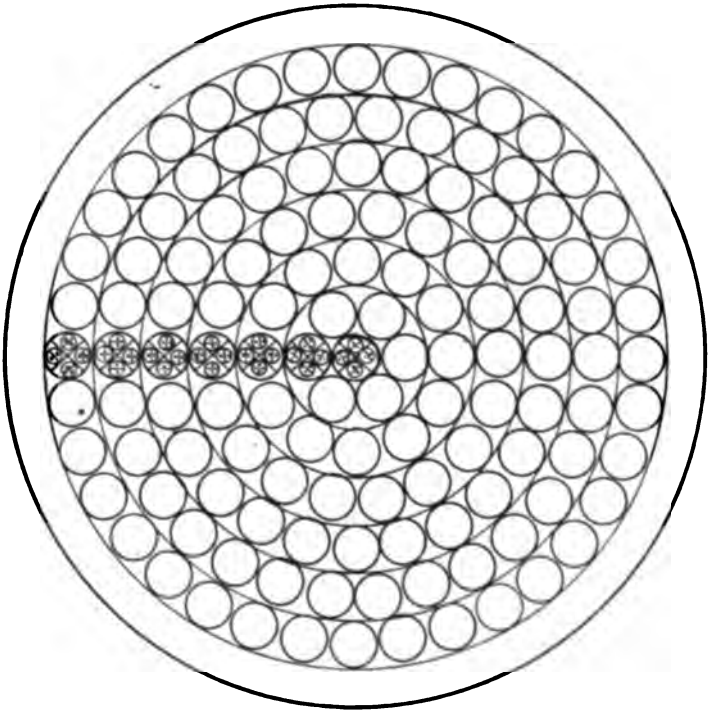


FIG. 6.

cores. Two 8-wire cores have been paired in the same way to form 16-wire cores.

A multiple twin cable of 10 lbs. conductor, containing 1,212 wires, provides facilities for utilising spare wires in the outer zones of a network in the manner referred to later. A sample of this cable, showing the stages of manufacture described above, is on the table, together with samples of quadruple pair and composite cables, illustrating the various methods of stranding described above.

Quadruple pair and multiple twin cable cores, say 2 in. in diameter, are sometimes surrounded by a layer of ordinary twin conductors or by one or more layers of screened conductors for telegraph purposes, this latter being the method adopted in the case of the former type in



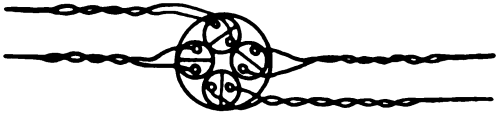


Diagram of Bunched Conductors.

FIG. 7.

connection with the West of England underground system (Fig. 8) and in the latter type in connection with the Northern underground cables (Fig. 9) and the cable now being provided between Leeds and Newcastle (Fig. 10).

The electrical results are given in Tables IV. and V.

Cables thus completely laid up ready for sheathing are dried in ovens or vacuum chambers to raise the insulation prior to sheathing with lead by passing the core through a lead press in precisely the same way as that adopted for other lead-covered cables.

Immediately after sheathing the cable is submerged, and when cool tests for conductivity and insulation are made. As regards the latter test, it is interesting to note that an insulation of from 10,000 to 20,000 megohms is frequently obtained, and that if the insulation of a core is allowed to fall much below 5,000 megohms the electrostatic capacity is raised.

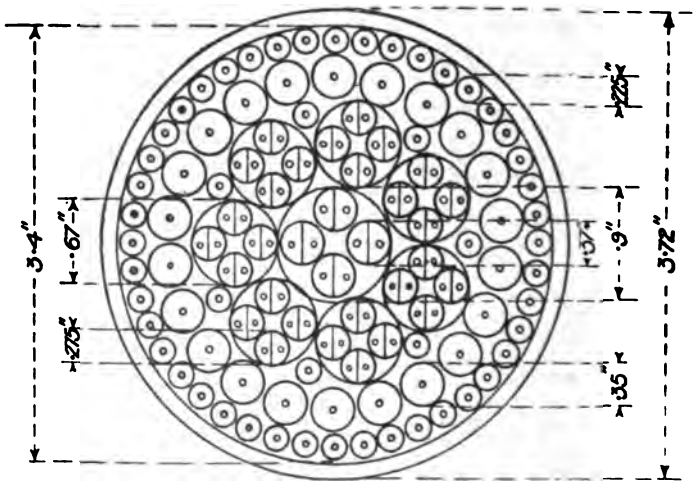


FIG. 8.

In this country these cables are almost invariably drawn into pipes, the sizes generally used being 3, 3½, and 4 in., joints being made at every 176 yards, or thereabouts, and sealed by a lead sleeve and carefully-wiped joints. These joints are tested under a pressure of 30 lbs. to the square inch, it being essential that the cable throughout its entire length shall be absolutely air-tight.

The method of jointing the quadruple pair and multiple twin cables is interesting, and a brief description will, therefore, perhaps be not out of place.

Although so far as the mechanical operations of jointing are concerned the ordinary methods are followed, great care is taken that the individual main cores on one side, whether they be of 4, 8, or 16 wires, are joined to similarly constructed cores on the other side of the joint, and that individual wires or pairs do not cross from one core to another.

TABLE IV.

AIR-SPACE PAPER-CORE CABLES.

Quadruple Core and Screened Conductor Cable. Tests on Completion.

Length of Section, 18 Miles (see Fig. 8).

Weight per Mile and Class of Conductor.	Total Conductor Resistance in Ohms.	Insulation Resistance in Megohms per Mile.	Capacity, Wire to Wire, in Microfarads per Mile.			Capacity, Wire to Earth, in Microfarads, per Mile.		
			Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
150-lb. loop	209·20	—	0·0658	0·0650	0·0653	—	—	—
100-lb. loop	318·50	—	0·0686	0·0658	0·0674	—	—	—
300-lb. bunched loop ...	104·60	—	0·0629	0·0629	0·0629	—	—	—
200-lb. bunched loop ...	159·25	—	0·0727	0·0714	0·0716	—	—	—
150-lb. wire	104·60	6,300	—	—	—	—	—	—
100-lb. wire	159·25	6,300	—	—	—	—	—	—
200-lb. single screened ...	80·14	8,100	—	—	—	0·1333	0·1333	0·1333
70-lb. single screened ...	228·34	13,500	—	—	—	0·1241	0·1241	0·1241
40-lb. single screened ...	392·90	14,400	—	—	—	0·0980	0·0966	0·0974

TABLE V.

Air-space Paper-core Cables.

Multiple Twin with Worming and Screened Conductors.

Length of Section, 29·77 Miles (see Fig. 9).

Diameter 2·75, 56–100 lbs.
12–150 lbs.
29–70 lbs. Screened.

Weight per Mile and Class of Conductor.	Total Conductor Resistance in Ohms.			Insulation Resistance in Megohms per Mile.		Capacity, Wire to Wire, in Microfarads per Mile.			Capacity, Wire to Earth, in Microfarads per Mile.
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Maximum.	Minimum.	Mean.	
100-lb. loop...	525·8	521·4	524·4	11,310	2,679	0·0609	0·0577	0·0603	—
150-lb. loop	344·6	344·6	344·6	11,900	4,465	0·0719	0·0719	0·0719	—
200-lb. bunched loop ...	262·9	260·7	262·2	—	—	0·0822	0·0763	0·0814	—
100-lb. wire...	262·9	260·7	262·2	11,310	2,679	—	—	—	—
70-lb. single screened ...	373·7	373·7	373·7	59,540	7,440	—	—	—	0·1032

The most convenient main cores are selected for jointing toget irrespective of colours.

As a general rule multiple twin cables are laid up in 8-wire cores, and the construction of the core and method of jointing are illustrated in Fig 11.

As each of the differently coloured pairs of wires is laid up with a distinctive lay it is necessary to follow a definite plan in jointing the

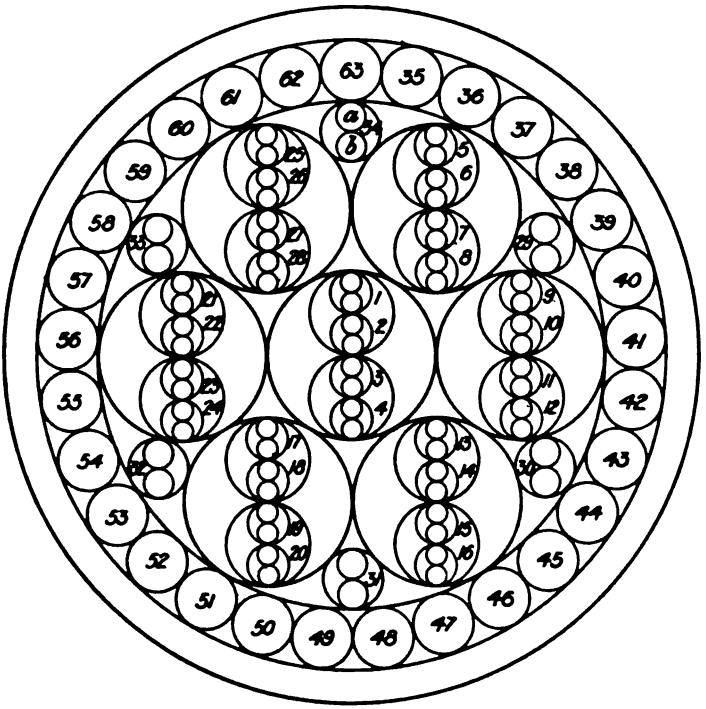


FIG. 9.—Showing Numbering as viewed from the Up-side.

NOTE.—The above is only a diagrammatic representation of the cable. In practice the wires will fill the spaces.

pairs together, in order that the greatest immunity from inductive disturbance may be secured. At each joint the coloured pairs are connected as follows: The colour first mentioned in each case is taken from the side from which the jointing is proceeding.

White pair to Green pair.
Red „ Blue „
Green „ Red „
Blue „ White „

Keeping these colour changes in view, a pair of wires on one side is joined to a pair upon the other, as a to a' in the figure. When this has been done, the second pair b, of the 4-wire core on the one side is joined to that, b', on the other, forming a through 4-wire core $e\,e'$, all the wires in which should be under one wrapping of paper.

The 4-wire cores, f and f', under the same paper wrappings as e and e' respectively, is next jointed in a precisely similar manner—*i.e.*, c to c' and d to d', thus completing a through 8-wire core, $g\,g'$, all the wires being under one wrapping of paper.

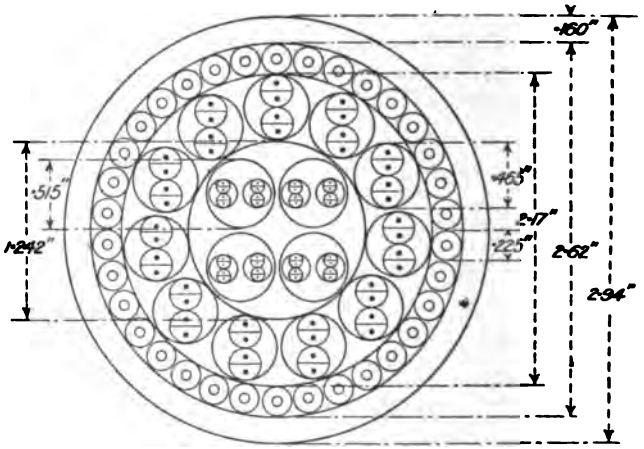


FIG. 10.

Similar precautions are taken in the jointing of quadruple pair cores, the pairs of which are of different lay, the colours of the pairs being red, blue, green, and white, in order of length of lay.

If pairs of similar colour were jointed together to form, say, a continuous mile length of cable, the red pair, being of shorter lay, would contain more wire than the white pair, its diagonal.

Consequently, when used as one the resistance of the red pair bunched to form an A wire would be slightly greater than that of the white pair bunched to form the B wire.

Care is therefore taken in jointing these cables that—

1. In any quadruple pair core similarly coloured pairs are not jointed together.
2. The diagonal positions of the pairs are maintained.

In quadruple pair core the red pair is diagonally opposite the white pair, and similarly the green pair is diagonally opposite the blue pair. At each joint if red is joined to green then white is joined to blue.

Each quadruple pair core has a paper wrapping of a distinctive colour and in jointing cores having dissimilar colours are always connected together.

In addition to the quadruple cores forming a cable, "worming pairs" may be added—that is, pairs which occupy the interstices between the cores, or between the pairs and the cores themselves.

To avoid parallelism of these pairs with the main pairs when bunched it is, therefore, necessary that the pairs worming a quadruple core should be crossed diagonally at each joint, the continuity of the diagonals being maintained.

Superimposing.—An economical method of using such cables is illustrated in Fig. 6 by means of a quadruple pair core, my practical experience of superimposing having been confined to the use of this type; but it is clear that similar results are to be obtained with the multiple twin type.

In the first quadruple cable cited Fig. 4 the unit conductors, weighing 100 lbs. per mile, would be used for distances up to 40 or 50 miles. At the end of these sections transformers would be installed, the primaries of which would be connected with telephone

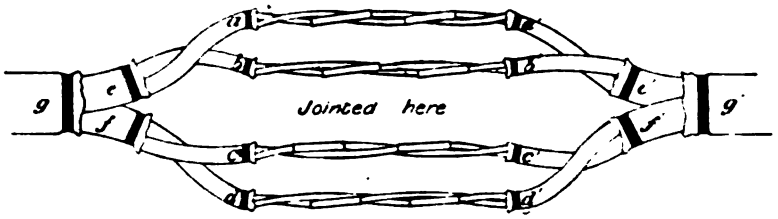


FIG. 11.

exchanges on the line of route between which traffic is probable. The secondary windings of the transformers would be connected across the A and B of the loop. The central point of the secondary winding being accessible, it would be connected to the central point of the secondary winding of a similar transformer connected to the A and B wires of the forward section of the same loop, this process being followed through the entire length of the cable. The diagonal loop having been similarly equipped at the same points throughout, there will be available between the extreme ends of the cable a loop of 200-lb. conductors of low mutual capacity. The only disadvantage would be the insertion of non-inductive resistances at three or four places; whilst the great economical advantage will have been secured of having heavy conductors for communication between the termini, which have already been utilised for intermediate communications. The shorter circuits would be subject to the losses common to all inductive circuits; but doubtless transformers could be designed for such a purpose which would reduce these losses to a minimum, although the type in general use would be perfectly efficient for the distances

indicated in this case. It is clear that, if four pairs forming a quadruple pair be symmetrically stranded around their common centre of yarn, the companion diagonal loops could be similarly utilised. Exhaustive experimental trials have been made on circuits 11, 33, 55, and 77 miles long in quadruple pair cables with complete success; and in addition superimposing has been successfully obtained by the insertion of transformers in the 200-lb. circuits and using as the A wire of an additional circuit two diagonal pairs of wires (400 lbs. per mile) and as the B wire the companion diagonal pairs of wire in the same quadruple core, thus obtaining seven circuits with four pairs of wire as shown in Fig. 6. There was a complete absence of cross-talk or inductive interference throughout the system.

As illustrating their utility, if cables of this type were used between Liverpool and Leeds, communication could be established between the following towns on the line of route by means of inductive circuits as described above :—

Liverpool and Warrington.	Oldham and Halifax.
Warrington and Manchester.	Manchester and Halifax.
Liverpool and Manchester.	Manchester and Leeds.
Manchester and Oldham.	Halifax and Leeds.
Halifax and Bradford.	Bradford and Leeds.

Also by spur lines off the line of route connected to the transformers, between, for instance :—

Liverpool and Salford.	Stockport and Bradford.
Liverpool and Stockport.	Stockport and Huddersfield.
Liverpool and Ashton-under-Lyne.	Rochdale and Huddersfield.
Salford and Rochdale.	Rochdale and Halifax.
Salford and Oldham.	Rochdale and Bradford.
Stockport and Oldham.	Rochdale and Leeds.
Stockport and Rochdale.	Rochdale and Wakefield.
Stockport and Halifax.	
Huddersfield and Leeds.	Bradford and Wakefield.
Huddersfield and Wakefield.	

In this way all the unit conductors will be utilised for short-distance communications between large towns having a community of interests, and therefore likely to provide an adequate traffic. At the same time conductors of double conductivity metallic circuit would be available for traffic between Liverpool and Leeds, with extensions by means of aerial lines to, say, Hull, Goole, Grimsby, York, and other places within about 100 miles of Leeds as a centre, and similarly with Liverpool as a centre.

Considerable lengths of two other types of quadruple pair cable have been manufactured, namely, (*a*) one containing 56 conductors, each weighing 100 lbs. per mile, 15 miles having been laid between Liverpool and Warrington; and (*b*) one containing the same number of wires, associated with 26 screened conductors for telegraphic

purposes between Manchester and Warrington, a distance of 19 miles. These cables are illustrated in Figs. 12 and 13 respectively.

Quadruple pair and multiple twin cables have also an advantage for junction lines between exchanges, especially where it is necessary

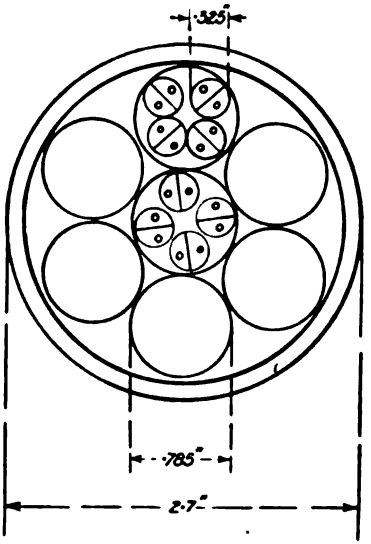


FIG. 12.

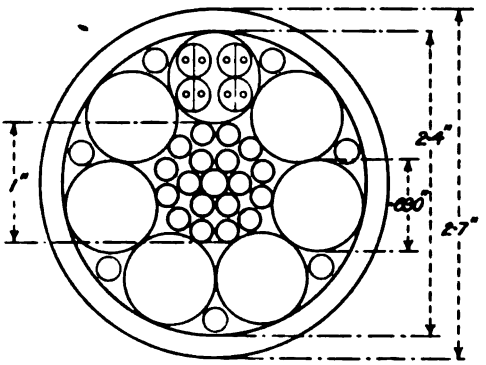


FIG. 13.

to provide connections for long trunk communications. For local purposes conductors of the usual gauge can be associated with those of larger sizes without reducing the number of wires, whilst the heavy conductors are capable of being bunched for special purposes.

The planning of an underground network for a local telephone

system on economic lines presents a fascinating problem, and time does not admit of the subject being fully dealt with in this paper.

Certain transmission standards having been agreed to for local and trunk purposes, and the equivalent lengths of various conductors in cable and open lines having been determined in terms of a standard cable, it is made evident that whilst conductors weighing 10 lbs. to the mile are necessary for many subscribers to an exchange system, there are a large number—probably the majority—of those connected to a well-placed exchange who could be efficiently served by a conductor of, say, 5 lbs. to the mile. It is doubtful, however, if so small a conductor could be safely provided in a cable of the ordinary construction, as the pairs of wires would require to take the strain of the large stranding machine used for building up the entire cable. In quadruple pair and multiple twin cables, on the contrary, pairs are first assembled in small machines into suitable cores, and these 8-wire cores so manufactured would be quite capable of taking the strain involved in the final stranding of the cable.

These two types therefore bring within practical limits much smaller conductors than are now used, with the advantage that whenever necessary they can be bunched to form 10-lb. or 20-lb. conductor circuits.

This uniformity of type should prove of great advantage in planning a local system. Not only would it prove economical in the way indicated above, but it would avoid a very considerable amount of idle spare plant which is now practically unavoidable with the ordinary systems of cabling.

If, to take a simple case, a uniform cable running from an exchange A to points B and C be tapped at B to serve subscribers, the wires concerned in the section B C are thrown idle. Engineers make a mental reservation, and sometimes provide the necessary ducts between A and B, for the provision of a new cable when required, for additional circuits to be distributed at B, or to bring into use the wires available in the form of idle spares in the B C section. As a matter of fact, many years often elapse before the additional cable in the A B section can be justified, and there necessarily must be occasions where it is never required. The spare plant above referred to is then useless. In quadruple pair and multiple twin cables every pound of wire in the B C section could be utilised, with the great advantage that a higher average conductivity would be provided for the circuits of greatest length. The same line of argument applies if the number of wires in the A B cable exceeds the number in the B C length and to cables for junction lines.

The proposed arrangement is not difficult to carry out, because the colour code adopted in the cable for indicating the variation of lay in each quadruple pair core renders it easy for a jointer to bunch the two wires of any desired pair in B C section and join them to the conductors of unit weight, as may be found necessary in the A B section above referred to.

Thus a rule may be adopted that the red and white pairs of each quad be first appropriated for subscribers, the white wire of the blue pair on the exchange side being connected to the white pair bunched in the forward section and the red wire of the same pair being connected to the red pair bunched in the forward section.

The white wire of the green pair on the exchange side would then be jointed to the green pair bunched in the forward section, and the red wire of the green pair to the blue pair bunched. The adoption of such a colour code would render mistakes almost impossible.

There is one other method of increasing the efficiency of the line, and securing approximate equality of treatment in connection with a telephonic network, viz., the economy of filling the pipe or duct, within certain limits, without regard to the number of conductors.

It should, I think, be regarded as an axiom of telephone engineering that, a given duct space having been provided at a heavy cost, a main cable should as nearly as possible fill it, and a low mutual capacity be secured where the wires in the outer zone are few. Thus, if circumstances should demand that a 2½-inch cable should only have a hundred conductors, these wires should not only be heavier if necessary than those near the exchange, but widely separated, so as to have a low capacity. It is conceivable that by this means a subscriber at a distance of more than two miles from the exchange may be able to speak over a long trans-continental trunk circuit with the same efficiency as one situated only a quarter of a mile from the exchange.

It is interesting to note the facility which exists in the quadruple pair cores for providing in cables primarily intended for trunk line purposes a large number of wires for junctions and subscribers' lines without detriment to the chief purposes, as all the helical interstices of the cores can be utilised for smaller conductors without increasing the capacity of the bunched pairs of the quadruple core.

It will perhaps be well to emphasise the fact that notwithstanding the great success which has been obtained by the use of telephone cables, even for considerable distances, it by no means follows that aerial lines cease to be necessary. Not only are aerial lines a vital necessity if long-distance telephonic communication is to be secured, but the enormous growth of this long-distance traffic makes it difficult to find room on the highways for all the wires required for that purpose. Moreover, the short-distance trunk circuits, largely placed in the underground cables, are not suitable for long-distance communication. As an illustration, although the great bulk of the traffic between towns such as Newcastle and North Shields, South Shields, and Sunderland respectively, is purely local, it is necessary between these points to maintain open routes in order that the towns mentioned may not be shut out from long-distance communication.

Taking the case of South Shields, although the cable designed for that route is exceptionally efficient for so short a distance, as compared with a 600-lb. backbone trunk circuit on poles, its use would

result in a person at Shields speaking *viâ* Newcastle to, say, London or Liverpool being as far distant from Newcastle electrically as a speaker in Dundee, 11 miles of cable being equivalent to 150 miles of open line.

I am afraid I have allowed very little time for considering the method of utilising these cables for telegraphic purposes, but Sir John Gavey, in his Presidential Address, gave some particulars of the results likely to be obtained, and since realised, between London and Glasgow.

The method referred to of working a telegraph circuit in a loop, and superimposing thereon an earth circuit is illustrated in Fig. 14, and it only remains to be stated that Hughes instruments have been very successfully employed between London and Glasgow, without a repeater, both by means of the superimposed circuit indicated in the diagram and also by the use of screened conductors. These screened

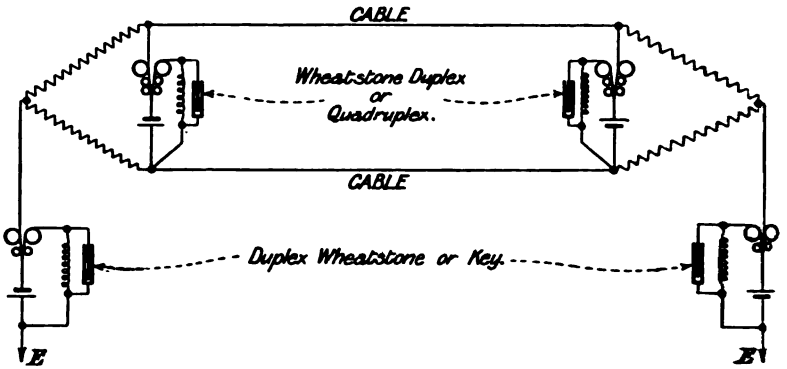


FIG. 14.

conductors have also been used for long-distance undulator circuits without a repeater.

A striking illustration of the efficiency of screened conductors is the 200-lb. wire used in the West of England underground, particulars of which are given in Table IV. It is probable that before the end of the next financial year conductors of this type will be available between London and Land's End, the landing-point of various Atlantic and other cables. The length of this circuit will be about 310 miles, and it is interesting to note how it compares with an Atlantic telegraph cable, and what results would follow the extension of an Atlantic cable by means of it, if such an arrangement be possible, in order that direct communication might be accomplished between London and the American stations, without retransmission at the cable stations. The length of cable from this point to Nova Scotia is 2,531 knots. Assuming that 1 mile of the screened conductor cable equals 1 mile of submarine, the 200-lb. screened conductor between this point and London

would represent about 310 miles of the Atlantic cable, increasing its length to 2,800 knots.

In the same way the cables landing on the West Coast of Ireland could be extended to London if a screened conductor cable were provided across Ireland, South Wales, and the Bristol Channel, to replace the open wires at present used for the Transatlantic traffic by this route in conjunction with a submarine cable—57 nautical miles in length across the St. George's Channel. If a cable of Atlantic type replaced this it would increase the length of Atlantic cable landed at Valentia from 1,847½ nautical miles to 1,904, and the screened conductor cable in England, Wales, and Ireland would be about 480 miles in length, thus making the circuit equivalent to 2,321 knots of Atlantic cable.

The fact that 1 mile of the 200-lb. screened conductor in question is roughly equivalent to 1 mile of Atlantic submarine cable—although the conductivity of the latter is about 2¾ times that of the former—is due to the capacity of the Atlantic cable being 0·42 microfarads per knot (0·364 per mile) compared with 0·133 per mile for the screened conductor.

It, of course, remains to be seen if the screening which is effective for ordinary telegraphy would be adequate if the conductors were joined to long submarine cable wires, but whether underground cable wires be stranded in pairs for use interchangeable for telegraphic or telephonic purposes, or provided with a screening tape for the prevention of inductive interference, they are a complete success for inland telegraphic purposes.

Discussion.

Mr. A. L. E. Drummond: I must congratulate Mr. Tremain on his paper, but I think that as the cables referred to are mainly long-distance ones, the title would have been better had the word "trunk" been inserted before the word telephone. I am somewhat surprised to note the extent to which Mr. Tremain deals with the question of superimposed working. Evidently he expects better results from underground cables than has been experienced with overhead lines. In this, of course, he is quite right, but he appears to be somewhat overloading the circuits with translators which must increase their liability to faults. With regard to the ideal condition referred to on page 717 of the paper, I consider that the tendency is now more towards decentralisation rather than centralisation, as was the case a few years ago, and think that, instead of putting in tapered conductors, it would be more practical to make a careful study of the district to be served, and plan out the cable scheme accordingly. I should anticipate some trouble with jointers if they had to follow the methods suggested, and this would more especially apply to the multiple core cables. With regard to these latter, I should be glad to go further into the question with the author, as the results of tests taken do not support the claims put forward by the designer. Mr. Drummond.

Mr. Drummond. I should like to know if the author has had any trouble owing to the use of coloured papers, as I remember some years ago a statement to the effect that there was a risk in using dyed paper owing to its possible corrosive action on the conductors.

Dr. Thornton. Dr. W. M. THORNTON: There are three electrical effects in a telephone cable: First, capacity, which retards messages by means of surface dissipations; secondly, inductive effect, which is to some extent an advantage in a telephone cable; and thirdly, resistance, which is an absorber of energy. With regard to the testing mentioned on page 724, if the megohms were down to 5,000 there must necessarily be water present which would affect the capacity. I should like to know if better speech is obtained on a superimposed circuit.

The enormous costs mentioned by Mr. Tremain are somewhat startling.

Mr. Johnson. Mr. T. B. JOHNSON: It is true that lead-covered cable has had great influence on modern telephone progress. The limits of speech with the use of india-rubber and guttapercha-covered cables are easily reached, and Mr. Tremain has had much to do with the development of the lead-covered cable. It is not always possible entirely to foresee the extent of service, so that in some cases it is a wise course to provide many small wires and bunch a certain number to supply subscribers living far away from an exchange. For this purpose multiple twin and quadruple cables are useful. As a matter of fact this course is at the present day in common use, two 20-lb. wires being, for example, bunched to make a 40-lb. wire. I think Mr. Tremain is too sanguine with regard to superimposing, not so much with regard to underground cables, but chiefly in cases where aerial wires are joined in circuit. Owing to faults it is impossible to maintain these so well as to shut out slight disturbances, which, although almost negligible in ordinary practice, would be noticed in telephones where the speaking efficiency is near the point of exhaustion. I should like to know what Mr. Tremain thinks of the idea of fixing copper tapes on alternate conductors only, instead of on every conductor. Intermediate conductors would be screened sufficiently by the presence of the copper sheath round neighbouring conductors, and much expense would be saved. It might be advisable to sheath all the single conductors in the inner layer which serves the most important circuits, but is the cost of screening all the outer conductors justifiable? Has it been found that tinfoil was unsuitable for screening material? Its cost would be much less than copper, but possibly there may be mechanical difficulties in the way.

Mr. Gaskins. Mr. T. W. GASKINS: Mr. Tremain gives the impression on page 716 that 606-pair cable is the largest used, but in Glasgow, Liverpool, etc., there is cable of 800 pairs in use. I suppose as formerly capacity tests are made at the same time as insulation and conductivity tests.

Mr. Cook. Mr. W. W. COOK (*communicated*): Now that reliable measurements of the transmission efficiency of circuits are so easily made it is

somewhat remarkable that claims for increased efficiency should be put forward and discussed without reference to any actual tests. Mr. Cook.

I do not know, and it would be of much interest if the author would tell us, to what extent multiple twin cables have been employed in practice by the Post Office, and what results have been obtained by bunching the conductors. Some tests on a table of this type were made by the National Telephone Company, and showed conclusively that circuits made up of two pairs of 10-lb. conductors gave results only 28 per cent. better than the single pair, while any further bunching effected no improvement whatever. Had the same weight of copper been used as a solid conductor a gain of 40 per cent. would have been attained. Fig. A shows the increased talking

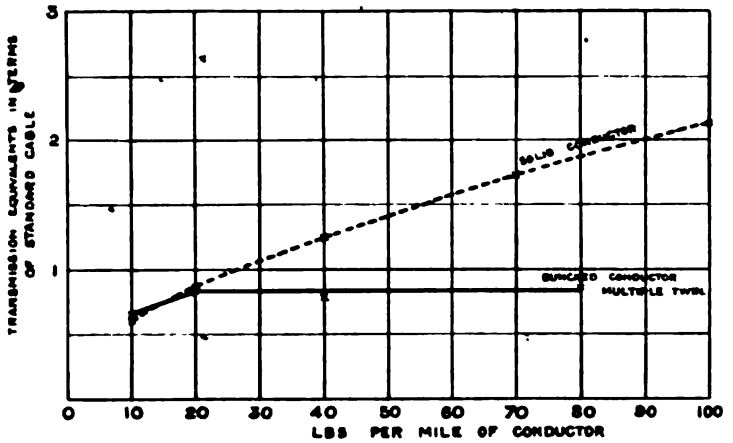


FIG. A.

efficiency gained by adding to the weight of the conductor in the ordinary manner as against adding to the weight by bunching conductors of uniform weight in this multiple twin cable.

If these tests are representative, and until the results of further tests on similar lines are given they must be so regarded, the claims for multiple twin cables must be restricted to the slight improvement gained by bunching two pairs, and even then it remains to be demonstrated that such a proceeding is economically justifiable. It must be borne in mind in this connection that for subscribers' lines on a central battery system the bunching of the conductors in an ordinary cable gives just as good results as a multiple twin cable would do when the resistance of the loop does not exceed 300 ohms, as under these conditions it is only a question of resistance.

I believe that the advocates of the K R law have now abandoned

Mr. Cook. it so far as aerial conductors are concerned, but it is apparently still not realised that even for cables it is only an empirical formula, the use of which must be confined to circuits with constants of ordinary dimensions. A simple experiment demonstrating this can be easily carried out by bunching the conductors of an ordinary telephone cable. The K R remains constant for different numbers of conductors, but the transmission equivalent is very different.

There are many other points in the paper which might have been discussed with advantage, but its main object seems to be the advocacy of the multiple twin cable, and only harm can result if the claims for this type of cable are put too high.

Mr. Martin. Mr. A. W. MARTIN (*communicated*): It is quite well known that the efficiency obtained by bunching conductors to form circuits of lower resistance than that of a simple pair is not so great as would be obtained from solid conductors of the same total weight occupying the same or rather less space. It is also true that for common battery exchange subscribers' lines, where the loop resistance does not exceed 300 ohms, the bunching of ordinary simple pairs produces as good a result as bunched multiple twin or quadruple pairs, but for appreciably longer lines the latter formation is the better. It should be borne in mind that when a cable is laid between two towns it is not always possible to foresee all that will be required of it, and there is certainly an advantage in having a cable, the conductors of which are arranged so as to be capable of bunching should the necessity arise, but it is not generally economical to twin more than two pairs together to form one group.

I should like to emphasise, however, that multiple twin cable was not primarily designed for bunching but for superimposed circuit working, and a little consideration will make it clear that multiple twin or quad-pair formation is essential in order that the *plus* circuits may be free from interference. The possibility of bunching is distinctly useful, but is of secondary interest.

Mr. Tremain. Mr. TREMAIN (*in reply*): As to the question of using aerial lines as superimposed circuits Mr. Johnson's doubts are justified, and, as a matter of fact, branch extensions are better carried underground. As regards underground cable, however, there is no trouble to fear. It is always fine weather in cables. In my experience with such cables I can say that not a fault has occurred in two years. It is necessary to pump air very rarely indeed. Once lead cables are laid they are practically sound. Only in such districts as Nantwich, where subsidence is likely to occur, is there any cause for anxiety. I agree it is not worth while superimposing on small local circuits. The point as to the principle of decentralisation is one I am not going to attempt to settle now. But if a cable is provided capable of giving satisfactory service to the person furthest from the exchange over the longest distance (say 2 miles), then obviously too much copper is used in uniform conductors for persons nearest the exchange who may be within a few hundred yards. A cable may easily require 5 to 6 tons of

copper per mile. In one system I came across 300 tons of copper lying spare which might have been used to advantage by bunching the conductors. I think that the junction systems are most complicated, and I consider that it is still debatable whether central systems having 10,000 or 15,000 subscribers are not the thing. Dr. Thornton's idea regarding the influence of the sheath on the capacity of diagonal conductors is new and acceptable to me. I have always put it down to cascade effect due to intervening conductors. I think that the big drop in insulation of paper cables if the slightest trace of moisture is present may be due to the fact that continual heating makes the paper more dense, thus reducing the intercellular air space. A point with regard to aerial wires coming down is that even if these are earthed there is no effect on other circuits in the superimposed system, as the earth virtually exists at the central point of two arms of a Wheatstone bridge which balance each other. With reference to screening, where there are two layers the screening of alternate conductors in the outer layer would probably be satisfactory, though it has not, so far as I am aware, been tried at present. Tinfoil is not strong enough mechanically, nor has it a sufficiently high conductivity to fritter down eddy currents. Copper tape can be made very thin by rolling, and can be manipulated in a rapidly revolving covering machine. Aluminium and also iron are now being used experimentally for this purpose, with what results I do not know. Mr. Gaskins is correct in saying that the largest telephone cable had 1,616 wires. Mr. Tremain.

Communicated: The claims for increased transmission efficiency in the case of the quad-pair type were based on actual results obtained on long trunk cables. The tests were, however, made some years since, before the present methods of comparison were available.

Unfortunately, I have had no personal experience of the working of multiple twin cables, but Mr. A. W. Martin, to whom that design is, I believe, due, has furnished a communication on the subject. A special feature of the quadruple form is that the wire-to-wire capacity of a pair formed by the diagonal pairs bunched is never materially higher, and may be made actually lower, than the wire-to-wire capacity of the unit pair, and the increased transmission efficiency is therefore very appreciable. This has been proved on cable circuits from 50 to 100 miles in length with aerial line extensions exceeding 200 miles in length.

Taking into account the transformer losses when the unit wires are bunched through a transformer, the plus or metallic circuit would be about 2¼ times as efficient as the transformer circuit, that is, if the transformer circuit were efficient for a 30-mile line the plus or metallic circuit would be equally efficient for 75 miles.

It is, of course, well known that the K R law does not hold good for circuits of dissimilar character, but a consideration of the K R of a circuit, when its self-induction is not lost sight of, is very useful when discussing in general terms the efficiency of various circuits.

It is obvious that unless the condition named above for obtaining a practically identical capacity for a double conductivity is secured, no

Mr. Tremain.

advantage can accrue from the bunching of wires in a telephone cable. In Table III. it will be observed that whilst the wire-to-wire capacity of 200-lb. pairs measures 0·0456 microfarads per mile, the same conductors bunched to form a diagonal pair in a quadruple core measures only 0·05, and that similar pairs of worming wires when bunched to form a 400-loop across the cable measures only 0·04 microfarads per mile. There can be no question as to the great electrical advantage obtained under such conditions.

THE MANAGEMENT OF ENGINEERING WORK-SHOPS.

By EUSTACE THOMAS, B.Sc.

(*Paper received from the* MANCHESTER LOCAL SECTION, *March 25, and read at Manchester, April 14, 1908.*)

The subject of this paper was chosen as affording a valuable incentive to the study of modern methods in practice, and not merely as proposed on paper.

By the courtesy of a number of gentlemen—to whom the author's grateful acknowledgments are due—visits were paid to works engaged in widely different manufactures, and the details of organisation and of the "paper" used were gone into at great length. The results of the author's impressions are presented after much thought with the desire that they may provoke useful discussion and interchange of ideas, on a subject which is yet far from its full development.

Variety of Systems of "Paper."—The amount of "paper" necessary for handing on instructions and keeping records and costs varies greatly, being very large in some works and quite small in others. There seems to be no generally adopted system and the same result is often achieved in quite different ways. It is impossible in a paper of this character to compare these systems in detail, and it is proposed rather to deal with the general principles and common objects of such systems.

General Shops and Specialised Shops.—Most of the shops visited, which had an efficient modern organisation, were specialised shops where the work was almost wholly standard, and non-standard work was discouraged. Such shops often reach a wonderful degree of efficiency and simplicity. The organisation of a general shop, where changes are frequent and much material is built to special order, is immensely more difficult; and efficiency is frequently much less. While this fact is usually recognised, such general shops exist in large numbers. As people really come to realise the difference at its full value, such general shops must diminish in number. And if it is possible to run such a shop efficiently it should be easily possible to run a specialised one; hence, much of what follows will be stated with the general shop in mind.

In one of the works visited, there were two quite separate establishments, in one of which meters were manufactured, and in the other switchgear. The one was specialised, the other general. The simplicity of the one when compared with the other brought the matter home to the author's mind in the most convincing manner.

To give these impressions some pretence of an orderly arrangement, the author has grouped them under the following heads:—

I.—Separation of head work and manual work and development of routine.
II.—Handling and distribution of material. Waste.
III.—Labour efficiency. Day, Piece, and Premium systems.
IV.—Cutting and non-cutting time.
V.—Execution of work to time.

I.—Separation of Head Work and Manual Work.

The general principle is that the manual worker should not have any avoidable head work to do.

It is generally agreed that the workman in every case should have a drawing, or even a sketch, to work to, fully dimensioned; that is, that the workman should have only manual work, and all head work should be done by the draughtsman or designer.

List of Material.—On the same principle a complete list of material should be prepared in the office, containing every single detail that may be required. The application of the rule is frequently carried out imperfectly. In one works every part of the gear was detailed in a printed specification with catalogue numbers, except the bolts, nuts, split pins, and other small store parts used in erection. Incidentally—erection was Day, and manufacture Premium work.

In hundreds of works the material is still requisitioned from the drawing by the foreman or the workman without a list. In every case where the list is not prepared beforehand or is incomplete, the workman becomes a head worker, and he is usually a very inefficient and expensive one. Moreover, a list *must* be got out by some one, and if this is done in the works it will have to be thought out and written out every single time that the job repeats itself. The certain result is preventable expense and loss of time. The list should be prepared in the office even if only one article is to be made, but in such form that it may be readily available for any future work.

List of Operations.—A still further application which is only seldom made, and only in the most advanced shops, is that there should be provided also a list of operations in every case where a new workman might possibly be in doubt. This applies particularly in some classes of switch work. Otherwise the foreman must give these instructions every time the work is given out, which implies preventable waste of time. He may forget or the man may do so, and that means imperfect work or waste of work and material.

If the job is given to a new man, the advantage is particularly great; but even if the same man gets the job his memory is not to be trusted. This is particularly the case where less skilled, or boys' labour is used.

List of Tools, Jigs, etc.—There are the same arguments for this list

as for the last. It saves head work, defects of memory, and consequently great waste of time, and makes it easy for the foreman to have the tools collected in advance by the labourer who collects material, and deposited ready on the man's bench or machine before he requires them.

Duties of Foremen.—The same principle deserves the most careful consideration in defining the duties of foremen. These may come under two heads :—

A. *Clerical or Administrative.*—Such as giving out work, seeing that there is no delay caused by waiting for material; watching the efficiency of the workmen, planning to get work executed to time, etc., etc.

B. *Technical.*—Methods, tools, and jigs, for executing work, for overcoming difficulties, for reducing cost of production, etc.

Probably in most existing shops, these two functions are combined, a foreman's clerk being often provided to assist function (A), and tool fitters to assist (B).

In some highly organised modern shops visited, the foreman was chiefly occupied with function (B), but the conditions were usually rather special.

The most modern tendency seems to be to give the foreman function (A) to carry out. In regard to (B) he must be technical enough to know if matters are not going rightly, and in such case set an expert tool fitter to study them out and do what is required.

This seems to the author essentially the right system, *especially when Day work is going on.* The shop will not work efficiently unless each man feels that the foreman is always about and vigilant, and this is impossible if he attempts to study out technical points. Equally he cannot possibly worry out technical matters efficiently if he is subject to constant interruption through his duties under function (A), and it is better to put on a man who can give the work undivided attention.

Human Element.—It is of essential importance to recognise that all employés are only human, and therefore liable to slack, liable to forget, and liable to neglect or to alter certain of their duties, unless these are defined and a check frequently taken.

In one works the responsible organiser stated that he had to be constantly on the look-out to see that routine duties were not neglected, and to nip in the bud numerous "improvements" on the system by individuals, which would render it unreliable. In another case one of these "improvements" was discovered while the author was walking round to examine the working of the details of the system.

Routine and Red Tape.—The best way to minimise these difficulties is to have a sufficient amount of red tape or routine, and to have the routine for each man written out. A sufficient amount of red tape is really essential, and also cheap, for it assumes that the work follows a well-worn and accustomed track. And, on the other hand, it is to be

remembered that discretion allows indiscretion, and the latter is costly out of all proportion.

Routine Books.—A routine is useless unless kept up by constant supervision. It is here that systems most frequently work badly.

The best way of preventing this that the author knows of is to have a routine book for each man who has routine duties. This to have columns ruled off for days or weeks. Each day or each week a tick or a date is put in the appropriate column to signify that that duty has been attended to, or to show the date to which that duty has been brought up.

All these routine books go to the manager at a stated hour each week, and he can glance through a large number in a very short time.

Weekly Inspection.—In the same way each week at a fixed hour the manager should walk round the works, and all books used should be laid out in readiness. A glance at the latest pages will show if these are being entered, posted, etc., as intended, or if an "improvement" is being made. The packing case records, as an example, often repay this trouble. At the same time any difficulties can be brought up for solution.

In this way the manager has his own routine, and should observe it as rigidly as he requires his subordinates to observe theirs.

Summaries and Abstracts.—In some of the works visited, all sorts of summaries and abstracts were prepared, which, if periodically inspected and acted on, would probably be more than worth their cost. In some cases, however, they certainly were not regularly examined. In such cases they are worse than useless, for they cost money needlessly, and they convict the management of slackness which will certainly be reflected through the works.

If used, it is worth while to have quite a number of these summaries, as long as their collection is made a mere mechanical matter not requiring skill or any but cheap labour.

The general principle is always to diminish head work, eliminate memory, and leave no excuse for forgetfulness or omissions, but all the time to make it easy to detect defects just as soon as they arise.

Application to Clerks' Work.—In one works the human element is recognised in a curious manner. In the costing work, forms have been prepared so as to eliminate writing as far as possible, and against each space are set full instructions for filling in. Moreover, additions and subtractions are done by a simple slide rule invented by the manager. This makes these operations merely mechanical, and the feeling of tiredness that is liable to set in near the end of the morning or afternoon is not expected to have so detrimental an effect as usual.

Inspection of Costs.—It is of little use recording comparative costs if they are not looked at. Where kept on cards, it is easy to place all cards on which entries have been made in a separate drawer each day. The manager can then inspect these quickly each day before they are put into their respective places.

II.—Handling and Distribution of Material.

Lists of Material.—Material *must* be booked, and this means that some one must write out a list of it. It is far the best way to do this in the office, even if only one article is required, and to preserve in this way a uniform routine system.

But the same list if prepared with thought for standard work, can serve several important purposes, plenty of copies being prepared and distributed.

A. The storekeeper marks it for material in stock or to order.
B. The stores issue goods from it to the foreman's auxiliary stores without further requisition.
C. The foreman can check by it all material at any stage.
D. The drawings having been cut up into as many parts as there are pieces or groups of pieces to be made, a copy of the list is also cut up and pieces attached to the divided-up drawings for the workmen's use.
E. On a further copy, against each item is marked the time by which it must be completed, in order that the whole of the work may go through to the date desired.
Each shop foreman must have his own copy marked.
F. A copy goes to the cost department. The work can be priced against this list in advance if required, and actual issues and returns can be checked against it.

If any one of these functions is omitted, delay, waste, or other trouble will follow, and the importance of the list is sufficiently obvious.

Arrangement of Lists.—Where work is executed in different shops, it is of assistance to subdivide the list accordingly.

Any assembled parts which may be used for other work are best given separate lists, as they may be manufactured for stock.

It is convenient to submit the pencil list to the foreman and to arrange in the order of importance of execution. It is quite easy to do this, and it saves time and thought to the foreman ever afterwards.

If several parts are given out together (as is regularly done in switch work) these can be grouped together, if this is attended to on the pencil list at first.

Catalogue Numbers.—It is well worth while to devise a system of catalogue numbers to cover all single pieces. A numerical system is very simple. An examination of a large number of drawings will enable all pieces to be divided up into a sufficient number of classes. Thus capstan rod work might be classed as 27, and it could be subdivided into sub-classes 27–1, 27–2, 27–3, and so forth. These class numbers are the numerators, and serial numbers are used as denominators.

A separate card is made out for each piece, and reference is entered to every drawing or job on which used.

The uses are numerous:—

A. This catalogue number appears on each drawing and on each list of material against each piece.
B. It facilitates comparison of costs.
C. It facilitates estimation by the ease of reference to all other pieces at all like it.
D. It facilitates standardisation by making it easy for any draughtsman to see what has been done before, and to use something already made if possible.
E. Patterns are marked with this number and stored in trays or spaces marked with the class number. This often saves new patterns by making reference easy to all existing ones.
F. The stores are arranged as far as possible to follow this classification.

The system is not nearly so difficult to put into operation as might at first be thought, and has obvious advantages.

Auxiliary Stores.—The percentage of time lost through waiting for material is always greater than appears casually. The orderly progress of the work through the shop may also be disturbed and the whole time programme disarranged.

It is probably well worth while to let the foreman have an auxiliary stores under his own control, with plenty of easily accessible shelves. All material for an order is delivered here and sorted out in a space prepared for it. With each lot is placed the drawing and even the job ticket. Any partially completed work is returned to the same spot to await assembly. Special tools and jigs can also be collected with the material and all given out together. With this system the foreman can see at a glance how the work stands, whether he is short of material, etc.

It is advisable to have plenty of tins of suitable sizes to contain small screws, parts, etc., so that these may be easily handled and not be mixed.

Shop Drawings.—These consist of pieces of cardboard carrying that part of the drawing required for any one piece or group of pieces given out to one man only at a time. On the same card is the list of material, cut off the general list, the list of operations, and the list of tools, gauges, jigs, etc. The separate cards are numbered serially and usually kept together. Those required for a job are distributed in the auxiliary stores in the space allotted. There should be some material to each card, if all material has been collected.

The above refers, of course, to such of the work as is small enough.

Losses, Scraps, etc.—If a rigid rule is made that small material shall always be returned to the stores when any part of the work is completed or is stopped from any cause, there will be fewer losses, and the man concerned may be made responsible. Incidentally it will check the giving out of too large jobs and the changing from one job to another before the first is complete.

The work should be checked at each stage for accuracy, and number of pieces; and any scraps should be dealt with and recorded, and orders for replace parts at once attended to. All scraps and defects in workmanship should be entered on the job ticket and in a report book which goes before the management.

In one works a weekly return is made of—

A. Materials scrapped through fault in the material.
B. Labour wasted through fault in the material.
C. Labour wasted through faulty workmanship.
D. Material wasted through faulty workmanship.
E. Cost of putting any jobs right if that is possible.

A slip cut off a duplicate of this return is pasted on to the cost card, and defects of workmanship are entered each week against the man on a special card giving his record for the half-year.

This system has been working for some years, and it is considered that the saving which has resulted much more than pays the cost of the clerical work.

Inspection at each Stage.—There is no doubt that this pays for itself even in such work as switch work. It is a sort of police system, and if relaxed trouble is liable to creep in at once. It is not very usual or systematic in many general shops, and particularly with such work as switch work.

Too Large Stock Orders.—Where both special or general work and stock work are going on together, it is easy to break off a stock job. This is always disadvantageous, and to avoid it—

A. Stock jobs should not be too large.
B. Work should be done on as few stock jobs as possible at one time, concentrating on these as many men as are available.

In this way no stock job need last long, and the liability to break off or to finish a part only of the order is consequently diminished.

This matter needs emphasising. Nearly all foremen have a natural inclination to get a large number of orders in hand at once, all progressing slowly and perhaps frequently hung up. If this is stopped there will certainly be less total labour used, and the orders will all be completed in less time.

III.—Labour Efficiency.

Day Work versus Piece or Premium Work.—If a number of shops are visited in succession, some working on Day work and some on Piece or Premium systems, the difference impresses itself most strongly. With Piece or Premium work there is not only a brisker air about, but also the author seemed always to notice a more cheerful atmosphere. Probably the reason is that with either the Piece or Premium system the man feels that he is working for his own benefit.

The following are some disadvantages of Day work, especially in general shops :—

The men slack off as soon as the foreman's vigilance relaxes at all.
Some men regard it as a matter of principle to make jobs last as long as possible with a view to increasing employment.
The men are quite content to wait for material.
The handling of material by the foreman is always less efficient.
Costing is uncertain and unsatisfactory.

Some advantages of Premium or Piece work are :—

Each man has an interest in the work.
The men press the foreman to give efficient delivery of material, and the foreman is thus placed between two fires.
Each job *must* have careful consideration before being committed to a price or time which may be hard to change.
Each job makes the estimation of new work easier.
The foreman has more time to plan his jobs and is better able to estimate for and keep correct promises of completion.
If the assemblers are on Piece or Premium work, they draw attention themselves to any inaccurate manufacture of parts coming to them.

Day Work to have Time and Price Estimated.—In cases where Day work seems necessary, it should be insisted on that a price and time are estimated for each job, even although these are not made known to the men. The actual price and time must be compared later with this estimate.

The effect is to force attention to all Day-work jobs, and in some measure to bring about the other advantages enumerated under Premium and Piece work.

But farther than this, it must eventually make the foreman desire to get Piece or Premium work in where he has been accustomed to give out Day work, for if a price has to be given in any case, it is easier for him if it is given to the man outright, and the man is working with him to keep the time down.

The simplicity, comfort, and general advantage of Piece or Premium work cannot be sufficiently proclaimed. So much so, that where appreciated every manager of a general shop will find means to introduce it to a much greater extent than is at present common.

Premium Work.—It was well known that with Piece work a man seldom attempts to earn more than about time and a quarter, for fear of getting the rate cut. This caused an uneasy feeling in the employers that they were not getting the best efficiency, and it was hoped by the introduction of the Premium system that this difficulty would be got over, a promise being made that the time allowed should not be altered *unless a new method were adopted.* In fact, the masters

hoped that they might be able to relax some of their vigilance, and that the men would of their own accord do their best in their joint interests. Such a golden vision was not likely to be realised. The men know quite well that if they make too much Premium *a new method will always be found.*

The author has been amused to find that the managers of some of the works visited have declared that the rate was never cut. Their responsible assistants, however, have usually acknowledged, on being pressed, that practically the same result was obtained by this plan of "finding a new method."

The practical result is that the Premium system, after all, requires just as much vigilance as the Piece-work system. It has the disadvantage of requiring rather more book-keeping, and of rather more difficulty in adjusting the price when a mistake has been made. If there had never been any cutting the older firms would have been placed at considerable disadvantage as compared with newer firms, and would find that they had been pioneering for such newer firms, who are enabled to take advantage of the improvements effected and set shorter times to start with. In actual practice, however, it is probable that the greater proportion of the rates fixed, especially in large machine work, are pretty correct, and there is not perhaps so much scope for any undue bonus to be earned.

Expert Check on Times Set.—Where it is considered that the best results are not being obtained, the author is convinced that the only way to improve matters is to have enough expert men who are paid well, and can be relied upon to work in the employer's interest. Such men, for example, may act as rate fixers. One or more of them can work on such of the jobs as seem to require checking, and they will advise on any changes that seem likely to be profitable. In particular they will seek economy in "non-cutting" times. It seems very desirable that the rate fixers should keep their hands in in this way, otherwise some stagnation is probable. Also if some system of remuneration for improvements they effect can be introduced, it will probably yield a very profitable return.

IV.—Cutting and Non-cutting Time.

On small work especially the proportion of non-cutting time is sometimes very great. In a certain rather tricky job a very experienced rate fixer set the following time: Cutting 16 minutes, changing tools 10 minutes, gauging 20 minutes, setting up and fixing 30 minutes. This, of course, was not quite an average job, but in particular the item for gauging is to be noticed.

Gauging.—There happened to be a number of surfaces to machine, and each to exact dimensions. "Gauging" included the actual measuring, and the successive short cuts, necessary to get down to the exact depth for the final cut.

A little thought will show how antiquated and wasteful are the

ordinary methods of doing this. A cheap gauge or micrometer is badly required, which will tell in a second or two to ordinary men just how far they are off the final dimension; and then means are required to set the tool forward just that amount. Micrometer heads on lathe screws are useless without the micrometer or gauge for showing how much remains to be taken off.

The introduction of some cheap device of this sort will easily effect an appreciable percentage economy.

Changing Belts.—With belt-driven machines and cone pulleys, the speeds usually change in not less ratio than 1·75 to 1 or even 2 to 1. In the latter case we shall on the average be working at just three-quarters of the correct speed, and the cutting time is increased one-third.

This is a very serious loss, and argues strongly the advantage of a gradual speed change device; also of some cheap speed indicator to be applied to the work and show instantaneously the rate of cutting.

But in an even simpler way losses constantly occur. It is usually not quite easy to change from one speed to another, and the tired man in particular will not take the trouble to speed up and down as often as perhaps he should.

One large firm doing very accurate work provides a handle, which automatically shifts the belt by pressure to right or left. There is no doubt the cost of this has been repaid many times.

Quick-change Drill Chucks.—A quantity of work comes under the radial or single spindle drill, and requires fairly frequent change of drills. Quick-change drill chucks, which enable the drill to be changed instantaneously without stopping the spindle, may easily save anything from 10 to 50 per cent.

Setting Work in Jigs.—In small and thin work the cutting time is often very little, and the setting and handling of the jig may be a large percentage of the whole. In one shop where the work was all repetition, and large numbers of very expensive jigs were used, the foreman estimated at a rough guess 25 to 75 per cent. of non-cutting time, a multiple spindle drill being used, and very good jigs.

Picking-up Tools.—In one very accurate and tricky job, requiring a number of operations to be performed from the same setting, and requiring a number of tools in successive use, the author was impressed with the small cutting time, and also with the loss in finding and picking up the exact tool required. A large block, having exactly as many holes as tools and gauges, and with these arranged in suitable groups, will save its cost many times over.

A careful study of this particular job enabled the time required for it to be halved, with considerably greater satisfaction in the character of the work turned out, and all by attention to these small details.

The above details will sufficiently emphasise the point that there is a large field open at present for improvement to reduce the non-cutting time as well as the cutting, and that employers may often profitably take obvious opportunities of economising which lie ready to their hands, instead of looking abroad for new tools.

Visiting Consultants.—In America, and in a few cases in this country, visiting consultants are called in to examine the works, its lay out, its organisation, and to suggest improvements.

Such men must have an experience which no one attached to a single works can possibly attain to, and should be able to exercise it without breach of confidence.

In any single concern there must be some tendency to stagnation, and there seems as good reason for the visiting consultant as for the visiting auditor, whose services are now regarded as essential, and taken as a matter of course.

V.—Execution of Work to Time.

In a general shop having many small jobs in hand at once it requires a very clever foreman to give times of completion of all work in hand which he can adhere to, and yet not have too much labour employed.

The author has devised a special indicator for the purpose, which gives the foreman a bird's-eye view of the work in hand, and of the capacity for work. It requires that time shall be estimated on all work in detail, whether on the Day, Piece, or Premium systems.

One or more suitable boards are laid out with horizontal grooves to represent the different men in classes according to employment, wages, etc.; some spare grooves are also allowed to each class. Vertical lines are drawn to scale to represent hours, days, and weeks. Fairly narrow strips of card are cut off for each job, of length equal to the number of hours estimated, and marked with the job number and date by which completion is required.

These are then set up in the grooves, always to the left of the date marked on them. If there is more work in hand than capacity in men some cards must go into the spare grooves. The card to the left in each groove is always the job in progress at the time with that man, those to the right being arranged in the order of present urgency. They can be reshuffled later as altered circumstances may seem to require. Thus the foreman or manager can see at a glance what work is likely to be late, what is the present capacity for new work, stock work, etc., what jobs are hanging, and where it is desirable to take on or discharge men.

The material labourer can also see what materials, tools, etc., are likely to be required soon, and get them ready. The cost of keeping up is small, and amply repaid by the advantages.

In conclusion, the author would recapitulate a few of the points which stand out most strongly before him :—

A. Make it unnecessary for the workman to *think* or *remember* what can be committed to writing, and he might forget.

B. Some red tape is necessary and cheap. Remember that discretion may also mean indiscretion.

C. Use routine books arranged fo easy weekly inspection.

D. Give every piece made a carefully chosen catalogue number, and use this everywhere.
E. Provide an auxiliary stores for each foreman where there is much small work.
F. Make use of the list of material in the numerous ways suggested.
G. Drawings should be divided up, and each detail given a list of operations and tools.
H. Get as many men as economically possible on to each order in progress, and so have as few in hand at any one time as possible, and finish each quickly.
I. Check standard jobs by expert labour, and reward impovements made.
J. Insist on an estimate of the time required for each Day work job.
K. For the sake of comfort as well as for economy displace Day work as much as possible.
L. Keep the attention directed to the "non-cutting" losses, especially with small work.
M. Keep the whole of the work under general view by means of a suitable foreman's indicator.

It should be pointed out again that this paper is merely a record of some impressions received, and does not pretend to be a system of works organisation; also that the author's interest being chiefly among small work, much of what has been said must be taken particularly to refer to this.

Discussion.

Mr. Gunther.

Mr. J. Gunther: There are certain points to which I might draw attention. Much naturally depends upon the class of work being done as to the type of organisation. In small work it is possible to specialise considerably more than in large work and to devise special arrangements. The author states that general shops exist in large numbers, and that these are as a rule less efficient than specialised shops. Well, I do not quite agree with that. I think a general shop, which is not taking every class of work, can be run quite as efficiently in its way as shops which are highly specialised, such as those dealing with small electrical appliances. Their method of handling a large piece is so well organised, and so well known, that the efficiency comes out really very fine indeed. As to each workman having a drawing or sketch, that goes without saying. In all well-organised places, the drawings have to be of the most complete character and fully dimensioned; and wherever possible, if it is a job likely to be repeated, the drawings should carry all leading particulars; and if there is a piece somewhat intricate, which requires a great deal of consideration as to how to deal with it properly, those operations, when once defined, should be written on the drawing, so that they can be repeated at any time. As regards

the list of materials, how far that list should go naturally depends upon the class of work. With regard to the list of operations, my own firm have one particular piece of work which is rather complicated, and has a large number of parts, possibly 100. This work has to be accurately carried out. We had considerable difficulty at first in making this particular piece. The chief difficulty was interchangeability, so that a number of different parts could be all made at one time, and when assembly took place that each piece would be an exact fit. We decided to make jigs for the whole piece, and when we did this we went a little further and made special tools for each piece. Altogether I think there were about 500 tools, and each set of tools and each jig carried a card with it giving the complete list of operations. Mr. Gunther.

As regards routine books, I do not quite see that in an ordinary works a routine book is necessary. As a rule the job that a man has given to him is not the same day after day, except in a place making one class of work; but no doubt where one man has to do each day the same class of work, or where the same class extends over several days, a routine book would be very advisable. As regards weekly inspection, possibly an inspection once a week may not be sufficient.

There is one point as regards numeration. We considered that point very carefully—the numeration of tools, drawings, and stock-pieces—and after examing all the different systems—and some of the systems suggested seemed to be very elaborate, one piece, for example, comprising perhaps a dozen letters and a dozen numerals—we came to the conclusion that the best thing was to sweep all such elaboration away, and to commence with the drawings. A drawing is D so-and-so, no matter what the piece is or what the shape is, it is D 1 up to 10,000 or more. The pattern bears a P and its number, and a stock-piece, which may be a bush or wheel or bearing, bears its number S1, S 2, and so on. The same with the tools; if there are any special tools, those would carry the letter T and its number, so there cannot be any mistake.

Coming to inspection at each stage, it is, of course, self-evident that as work goes along some system of inspection is necessary, either by foremen or by men specially detailed for this class of work. As regards stock orders, this is often a very difficult matter to arrange, and I think that the system which we adopted, which was not entirely new, is the best. This is, that when a particular article can be made to stock and used in connection with several other pieces, the number made for stock should be worked on the maximum and the minimum system. With regard to Premium and Piece work, I am afraid that Premium and Piece work are going out in engineering works. When dealing with non-union and unskilled labour, and especially with small repetition work, it is easier; but when dealing with union workmen, and the work is of a larger class, and few jobs are entirely alike, it is rather too big a task.

Mr. H. Bevis: With regard to the question of the duties of foremen, I think undoubtedly we cannot over-estimate the question of the value of foremen. A good deal of the efficiency of the shops depends upon Mr. Bevis.

Mr. Bevis. the foremen, and my idea is that they should be employed more exclusively under clause A (p. 743). I think it is quite a mistake to give them the technical points such as indicated in clause B; this should be rather for the tool shop or drawing office, and it should be his chief aim to finish and produce the work under clause A.

As regards the question of weekly inspection, I am afraid I should not like to carry out Mr. Thomas's suggestion of having a fixed day once a week when I should be round the works, and at a certain spot at a certain time. I prefer to be there frequently and when I think I will; I find it makes much more efficiency. I am in agreement with Mr. Thomas on the question of having statistics. I believe they are most valuable items, and pay for themselves over and over again—that is, if properly utilised. I find them of considerable assistance and always very instructive, and very often they enable one to get to the root of a trouble that would otherwise take a long time to find out. The paper rather conveyed to my mind that it concerned large engineering works, and not such where there are large quantities of small work. Coming to the question of auxiliary stores, I think that it is an essential thing to have what we call sub-, or auxiliary, stores. I consider that the main stores should keep raw material and everything that is common to several departments. I should not allow my sub-stores to keep, say, screws, bolts, nuts, etc., that are used by three or four different departments; they should be kept in the main store. There is quite enough in the sub-stores of material that is common only to the department in which it is used, and in such sub-stores that is the only material that should be kept there. To obviate the possibility of material not being in the main or sub-stores when required, I believe in having assembly rooms—that is, if there is a job in hand that goes to an assembly room. The whole of the parts are assembled, and the job is never put out to the bench until they have got the whole of the parts, and until it is so assembled the job should never be given out. There is one thing that I should rather think is wrong on page 748, where it is stated: "If the assemblers are on piece or premium work, they draw attention themselves to any inaccurate manufacture of parts coming to them." There is no doubt this is some check, but where one is making quantities of stuff I think it is then rather too late. The time that they should be checked up is when it is being manufactured in the early stages. If it is only going to be sent back when it is found not to fit, it is too late to save the loss, as all the parts will have been made wrong, and the job would be kept waiting for this particular one to be made correct.

With regard to the visiting consultant, I am afraid that is a very good name only; and it is like the card system, much overrated. A lot of people think that the card system will cure everything, and some people think that a visiting consultant by coming to see our works can tell us everything better than we can ourselves. I believe the best thing is if we can get our friends to allow us to see their methods, and put the various methods together and select the best.

Mr. A. ECKSTEIN: I am afraid I rather disagree with Mr. Bevis as to the application of the paper to large engineering works manufacturing a heavy class of work. It strikes me, if anything, that the title is somewhat misleading. I think that right through it most decidedly refers to repetition work of a small nature. Mr. Eckstein.

I do not believe in making a working man rely absolutely upon red tape, and I think it will be a bad day for this country when he becomes an automatic machine; we always encourage our men to use their common sense. As regards the weekly inspection, I am afraid Mr. Bevis has forestalled me, and I agree with his remarks.

As regards the auxiliary stores, I think there is one point that Mr. Thomas has not dealt with, and that is, I do not quite see, if a job has to be stopped, as is bound to happen, by what system the material would be then returned to the main stores. An auxiliary store, I should think, must mean a small store or a place provided in absolute vicinity of the bench, where the workmen have a certain amount of material to see definite orders through, but any such auxiliary stores must not be allowed to develop into a number of general stores. With regard to the visiting consultants, I should think this might be excellent for a comparatively small works, who cannot afford to have a staff of experts, and perhaps also for works whose representatives do not get an opportunity of travelling with a view of inspecting modern improvements in other factories; but for a large works with a staff of expert people I should think that a consultant would cause in many cases more mischief than good, as in the short time he would spend at the works he could hardly fathom matters as well as the permanent staff, and might possibly give wrong impressions to a Board of Directors.

Dr. C. C. GARRARD: One of the most important things about the management of an engineering works of any magnitude whatever is the cost-keeping. In a large works it is impossible for the management personally to attend to the detail running of the works. It is necessary for the management to have an automatic and ever-ready indicator of the efficiency of the works always before it. The functions of the shop superintendent and foreman must be organised in correlation therewith. The costs of each individual process over which the respective foremen have control must likewise be automatically and regularly brought before them. Cost-keeping, in fact, is not simply a means whereby the actual costs should be recorded and used as a basis for estimating work. A system which gave the costs of a job several weeks after the same is completed would do if the matter be regarded simply from this point of view. In my view, however, a proper system of cost-keeping is much more than this. It should serve as a method of management, and transform a merely qualitative works control to a definitely quantitative one. According to this method, every job or process should be actually priced in money terms before it is started, and the work controlled during progress, not by a merely qualitative judgment as to whether the workmen are working at a proper rate, but by the actual costs being kept from hour to hour, so that at any Dr. Garrard.

Dr. Garrard.

instant the management can know what any process has cost up to that particular moment. Of course, these principles are recognised in the Piece work and Premium bonus systems. In both these systems of putting work through, the actual processes are priced before the jobs are started. I think, however, the same principles should apply when the workmen are working Time work. There is even more reason to apply them to Time work, as with the Piece work or Premium bonus systems the workmen themselves have a stimulus to keep the cost within the specified value, which with Time work is not so.

Regarding the relative merits of the Piece-work and the Premium bonus systems, I prefer the former. The great objection to the latter is that the workmen get the idea that they do not receive the whole benefit of their extra exertions.

I have thought that a short description of a system of cost-keeping that I have originated in a works manufacturing electrical transformers and instruments might be of interest. The previous system in use in the works in question had been the Lewis system. For such a works this system is unsuitable. The foundation of the Lewis system is the job card which each man receives. On one side of the card is the space for the man's time; on the other, for the material used. Thus the workman has to go to the stores to draw out material and get it entered on his card. This is, however, very unsatisfactory. I introduced a modification of the Lewis system with additions. For every job which is not an absolutely standard article with a constant selling price, an estimate card is made out in the drawing office before the job is put in hand. It is the duty of the works management to see that the article manufactured comes within the estimate. Each shop has its own stores, and the material required for every works order number is issued by the stores as requisitioned by the foreman. For standard articles standard printed requisition sheets are used to avoid waste of time in writing. The material costs for each works order number are kept by the cost clerk who works in this stores. All issues are entered on cards. There are four different coloured cards used. These are for stock materials from the stores concerned, castings from the foundry, materials from other departments, and materials from the general stores. Every item goes through the shop stores, however, and the only object of dividing the cards in this manner is to facilitate departmental book-keeping. The total of the four cards gives the total material costs on any works order number. When the works order number is complete, a summary card is made out and filed in the drawing office; this, together with the estimate card and the labour analysis card, are filed together in special drawers like a card index. Reference to the costs of any works order number at any time is, therefore, a very easy matter.

As regards the labour, each works order number is divided up into a number of job order numbers corresponding to the different processes. Time-work cards or Piece-work cards are issued to the workmen for each job order number as the case may be. When each job

is finished the sheet is returned to the job clerk, who enters up the total time and cost in his time-book. The total hours in this book must, of course, agree with the total hours as shown by the works' gate-time record. The labour costs are entered up on the job number card and summarised on the labour analysis card, a copy of which analysis is kept in the drawing office record as explained above. Dr. Garrard.

As regards stock order numbers, these are treated in exactly the same manner as works order numbers, and the stock parts, when completed, go into the stores at the price they have actually cost, and are also debited out on the various works order numbers at the same price. As many similar articles as possible are put through on each works order number. These may be for stock or for definite orders as the case may be. At any rate, the works order numbers are so arranged that the total cost on the works order number when divided by the number of like articles made gives the individual cost.

As regards pricing stock parts, these are priced at the actual cost in labour, material, and testing plus shop establishment charges. The shop establishment does not include general establishment charges, which remain more or less unaltered whatever the output. The shop establishment charges include all shop charges which vary with the output, such as general labouring, supervision, etc., and which are directly under the control of the shop management. These vary with the output, but not so fast as the output. They vary between 40 per cent. and 60 per cent. of the labour cost. All goods made are costed in this manner, and, as an inducement to the reduction of cost, a bonus is paid based upon the difference between this shop cost and selling price.

In order to be able to control costs of standard articles, I have found it a good plan to plot the costs in the form of curves. It is somewhat difficult to obtain regular curves, the difficulty being due in part to variations in the cost of certain of the processes which are unavoidable, but I do not claim that the accuracy of such curves is greater than 5 per cent. Still, the general tendency of such curves from month to month affords a very fair basis for judgment of the way things are being managed.

Mr. EUSTACE THOMAS (*in reply*): I do not think there is much I have to say. With reference to the question of weekly inspection, I do not mean that the manager is to walk round the works each week just to try and find things wrong in the works itself, but only that he should inspect the paper and the books, because I have noticed myself in very many cases where books are supposed to be kept up as a matter of convenience, and where it does not follow that any system of book-keeping may be necessary, these matters are liable to get neglected. What I suggested was where there are books of this sort, such books should be inspected once a week. They can be gone through in a very few minutes, and one only has just to glance over the last few pages to see whether the various particulars are being filled up and kept to date. Mr. Thomas.

With regard to the catalogue numbers, I still think the matter of catalogue numbers is rather an important one. Mr. Gunther spoke

Mr. Thomas.

about the numerous letters and figures which are involved. Well, I think that is the very reason one wants the catalogue numbers. We found in doing a great deal of general work, and having to design special pieces for special apparatus, these were apt to get associated with a particular job which was forgotten in a very short time. A new draughtsman coming in, and having no recollection of this job, would start and re-design it over and over again, and parts get multiplied out of all reason.

One speaker asked how far the remarks which I have been making have been embodied in our own works. I am afraid to a very small extent. I took up this subject because I recognised how much advantage we should get by carefully studying the matter out. I have been giving very great thought to what I have seen in other works and others systems, and I am hoping to embody everything that has been said in our own works, which will be of considerable advantage. I think that everybody will eventually come to the idea that the foreman should have the duties under Section A most particularly. With regard to the matter of the visiting consultant, of course, I do not know how far that would work out, but it does seem that it should be possible for a consultant to do considerable good. At any rate, it would not entail a very large expense, and I merely make the suggestion for what it is worth. It is quite true, and it is very regrettable, that workmen as a whole have deteriorated very considerably, in consequence of the system of manufacture adopted. It is necessary that we should specialise to a very great extent to get efficiency. I am dealing, of course, with work that is not absolutely simple and straightforward, such as switch work. It pays one to go to what looks like an absolutely exorbitant and absurd expense in preparing certain things to carry out a job. It pays in the end, perhaps not in the mere manufacture of the article, but afterwards in the diminished cost of assembly, in the less time the job hangs about, the less anxiety, and the better satisfaction the job gives both to the makers and the buyer.

THE ELECTRIFICATION OF THE MANSFELD COPPER MINES.

By H. R. SPEYER, Student.

(*Paper read before the* STUDENTS' SECTION, *in* LONDON, *January* 15, 1908.)

In view of the attention that has recently been called to the working of gas-driven generating plants, a description of the Mansfeld Copper Mining Company's blast furnace gas engine central station is of special interest. This station, which is the largest of the three owned by the Mansfeld Copper Company, is driven by two 1,300-H.P. Oechelhäuser gas engines.

In order to determine the heat equivalent and quantity of blast furnace gas available at the Krughütte foundry, adjoining the central station, various experiments had to be carried out, and it was found that the four furnaces were able to deal with 625 tons of ore per hour, with a coke consumption of 215 kg. per ton of ore. At the time of making these tests the blast furnace gas was being used in conjunction with mineral coal for firing boilers; this procedure was, however, naturally somewhat wasteful, as the following figures prove :—

The firing of the boilers with blast gases required approximately 36,460 calories per horse-power-hour, and as the heat equivalent of a horse-power-hour is 638·8 calories, with this method of working only 1·74 per cent. of the theoretical heat value of the blast gases is used to advantage. By employing these gases, however, for driving gas engines, a far more favourable result can be obtained, for as the heat equivalent of the gas required per horse-power-hour is only 3,000 calories, as much as 21·2 per cent. of the theoretical heat value of the gases is used.

The two influential elements deciding the question as to whether the gases were suitable for driving gas engines were their chemical constituent and the quantity of foreign matter present.

The heat value of the blast furnace gas depends, as is well known, upon the quantity of carbon monoxide, hydrogen, and methane present. In this particular case the quantity of hydrogen and methane was small enough to be negligible. The results obtained proved the proportion of carbon monoxide to be relatively small, especially when compared with the average value of that contained in the gases from iron ore furnaces. This circumstance naturally emphasised, all the more, the question as to whether the gases in this case could be economically

used for driving engines. Practical experience has, however, proved that in general and, of course, within certain limits, the poorer the quality of the gas the better suited it is to the work in question.

The state of the gas on leaving the furnaces was very unfavourable for working the engines, owing to the presence of much finely-divided dust. In the experimental plant which was erected, however, a Theisen's patent centrifugal contraflow gas washer was used, and gave such satisfaction that no further anxiety was necessary on this score.

Horse-power Available.—This depends naturally upon both the chemical and heat equivalent of the gas and the quantity obtainable. The average percentage of carbon monoxide contained in the gases from the Krughütte foundry is approximately 21·65 per cent., which is equivalent to 650 calories per cubic metre of gas—on the basis that 1 per cent. carbon monoxide is equivalent to approximately 30 calories per cubic metre of gas. The average quantity of gas available is 21,000 cubic metres per hour, therefore the available horse-power at the Krughütte is approximately 4,500 B.H.P.; this on the assumption that the gas engine requires 3,000 calories per B.H.P.

Allowance must be made for the fact that the furnaces are cut out from the main delivery gas pipe when undergoing the process of charging, tapping, and cleaning, and it may sometimes happen, in spite of strict contrary orders, that these operations are carried out on more than one furnace simultaneously. It is therefore not safe to take the continuous quantity of gas available as being more than approximately two-thirds of the actual; this, then, brings down the horse-power to approximately 3,000; and making a still further allowance that the heat value of the gas may decrease 10 per cent., we get the ultimate available effective horse-power under the most unfavourable circumstances as 2,700.

The Krughütte Gas Engine Central Station.—In the original laying out of this station it was not deemed advisable to take advantage of the total horse-power at once, since the electrification of the mines can only be proceeded with gradually; the influential factor underlying the initial move was that there should be as little disturbance as possible in the continuous working of the mines undergoing this important change. Therefore on this account the central station has at present been laid out for a horse-power of 2,600, comprising two units, each 1,300 H.P. Ample arrangements have, however, been made for increasing the number of units as the growing load warrants their erection.

Gas Conveyors.—The blast furnaces of the Krughütte are connected up to two parallel running gas trunks having an internal diameter of 1,600 mm. and 1,000 mm. respectively. The furnaces are so connected up to the gas pipes that each and all can exhaust in either the one or the other as required when cleaning operations are in progress. These two gas trunks serve to lead the blast gases to the Theisen house, where they undergo their cleaning operation.

The Cleaning Plant.—The gas cleaning plant consists of three Theisen patent centrifugal contra-flow washers. Each washer consists of a conical metal casing lined with a wire meshing; revolving within, at a periphery speed of 3,000 metres in a minute, is a drum fitted with spiral blades. The blades are so formed at their ends as to draw in the gas at one end of the casing and expel it at the other. Water is admitted through an opening at the side of the casing and is finally sprayed by the blades, being caused by their spiral form to flow in the opposite direction to the motion of the gas, constituting the contra-flow action. The water, on leaving the cleaner, is conducted to a settling tank, where the deposit quickly settles and the water is used over again. It may be mentioned here that the deposit contains over 20 per cent. lead; it is therefore stored up, and afterwards put through a process for liberating the lead. The gas, on leaving, is passed through a Theisen's patent vapour separator in order to be dried. The action of the apparatus is continuous, and as the bearings are fitted with ring lubrication practically no attention is required. The gas, before reaching the actual washer, is passed into a preliminary saturator, where it is robbed of the heavier dust.

The three washers at the Krughütte are together capable of dealing with over 30,000 cub. ft. of gas per minute, and use in all approximately 200 gallons of water per minute. The gases, before entering the washer, contain approximately 17 grammes of dust per cubic metre, and after leaving, only 0·003 gramme per cubic metre, a fact which speaks very well for the efficiency of the Theisen plant.

The dust consists principally of—

Lead	33	per cent.
Zinc	22	,,
Sulphur	13	,,

The lead is present in the form of lead oxide PbO, and zinc in the form of zinc-sulphate.

From the cleaning plant the gas passes into a reservoir having a capacity of 500 cubic metres. The function of this reservoir is to balance the small changes in the quantity of gas coming over from the furnaces and to act as booster in times of sudden variation of the electric load. It is capable of feeding one of the 1,300-H.P. gas motors for six minutes. Naturally as the output of the station is increased a second and larger reservoir will be required.

A duplicate system of piping serves to conduct the gases from the reservoir to the Oechelhäuser gas engines.

Mechanical Plant.—The Oechelhäuser type of gas engine was chosen on account of its well-known adaptability for working efficiently with blast furnace gases, and further on account of its extreme simplicity, giving the plant therefore a high working safety factor. The principle underlying the working of an Oechelhäuser gas engine is too well known to require a detailed description. Two sets are installed, the normal output of each set being 1,300 H.P. at 125 revs.

per minute when worked with blast furnace gas possessing approximately 650 calories per cubic metre at 0° C., and at a pressure of 760 mm. The flywheel effect has been so calculated as to allow for a satisfactory parallel running of the two machines.

The gas engines are started up by means of two air compressors driven by 3-phase motors. The water used in the cooling of the cylinders is raised up to a cooling tower by means of electrically-driven centrifugal pumps, and is afterwards stored up in two large tanks and used over again. The necessary water for cooling the exhaust gases is run off into a pit, situated in a neighbouring field, being too contaminated for further use.

These two gas engines have now been working for more than two years, and have given every satisfaction when working, either singly or in parallel.

The Electrical Plant.—The main electrical plant consists of two Siemens-Schuckert 3-phase generators with revolving outer magnet poles. Each machine is designed for an output of 1,000 k.w. at 3,000 volts when running at 125 revs. per minute and 50 ∿.

The generators are mounted between the two halves of the gas engines. The excitation is obtained from two motor-generators; a 220-volt battery is also provided, working in connection with a booster, in parallel with the two motor-generators. The motors driving the exciters are of the ordinary 3-phase star-connected type, wound for a pressure of 3,000 volts.

In addition to the two 1,000-k.w. machines there are also two small 100-k.w. 3-phase machines coupled up to two small Körting gas engines. These were originally for pioneering work. The switchboard and busbars have been so designed as to allow for considerable extension as more units are added to the plant.

Table I. has been prepared to show the actual working results obtained in the station. The average working cost of a unit for the first six months of last year was 0·16d. After deducting 10 per cent. for depreciation and 5 per cent. for interest, an average monthly profit of approximately 44 per cent. was obtained. The curves depicted in Figs. 1 and 2 have been compiled from the actual data expressed in Table I., and serve to show at a glance the economical working of the station. The results for the month of June are not so favourable as the preceding owing to the new Hohenthal generating station being put on the Krughütte line. The current consumption, therefore, from the Krughütte as well as the revenue is diminished while the station running expenses remain practically constant. The fact is once again emphasised how much cheaper it is to generate energy from large units put down centrally than from smaller units scattered over the distribution area. The load for which the Hohenthal station is constructed consists of two powerful electrically-driven pumps for holding the mine free of water.

The Hohenthal Central Station.—The generating plant of this station consists of two Siemens-Schuckert 3-phase star-connected generators,

TABLE I.

The Working Results of the Krughütte Central Station.

Month.	Running Time in Hours.	Running Sets.	Units Generated.	Average Load over Running Time.	Capacity of Running Sets (in Running Time).	Capacity of whole Station. Possible Units in Running Time.	Running Plant Load Factor.	Plant Load Factor.	Total Units Sold.	Total Working Costs.	Working Cost per Unit.	Revenue.	Profit.	Per Cent. Profit after deducting 10 per Cent. for Depreciation and 5 per Cent. for Interest.
		Kilowatts.		Kilowatts.			Per Cent.	Per Cent.		£	d.	£	£	Per Cent.
January	701·5	1,080	330,599	471·1	1,472,200	3,578,940	33·3	13·7	407,508	435·75	0·176	670·89	245·14	42·5
	646·0	1,080	149,061	230·7										
	94·0	100	5,120	54·5										
	75·0	100	4,020	53·6										
February	650 45 m.	1,080	391,740	601·7	1,408,372	3,960,080	39·1	13·8	439,872	435·45	0·159	712·35	276·90	48·5
	615 45 m.	1,080	140,920	228·6										
	206	100	6,120	29·7										
	206	100	6,120	29·7										
March ...	700	1,080	265,150	378·8	1,461,760	3,228,480	36·9	16·7	443,698	470·10	0·176	738·61	268·51	42·1
	653	1,080	272,540	418·0										
	8	100	400	50·0										
	8	100	400	50·0										
April ...	665	1,080	190,137	285·9	1,489,320	3,541,180	39·5	16·6	484,745	455·76	0·157	759·60	303·84	51·5
	701 30 m.	1,080	388,073	554·7										
	76	100	2,680	35·2										
	58	100	2,200	38·4										
May ...	662 30 m.	1,080	177,540	268·1	1,528,500	4,329,420	39·1	13·8	479,824	472·59	0·159	768·49	295·90	47·5
	710	1,080	400,420	563·9										
	231	100	8,830	38·2										
	231	100	8,820	38·0										
June ...	388 30 m.	1,080	97,942	250·2	1,245,380	4,550,960	42·6	11·8	436,800	456·50	0·171	690·10	213·60	31·7
	700	1,080	401,628	573·8										
	309	100	18,380	40·4										
	309	100	18,480	40·4										

each with an output of 3,150 volts, 165 amperes, with a power factor of 0·79, running at 125 revs. per minute and 50 ∿.

The excitation is obtained from a 3-phase continuous-current motor-generator, and in the first instance from a small direct-coupled steam-driven dynamo.

The steam-driven units of the generators comprise two horizontal compound Sulzer engines, each with a normal output of 750 H.P. and

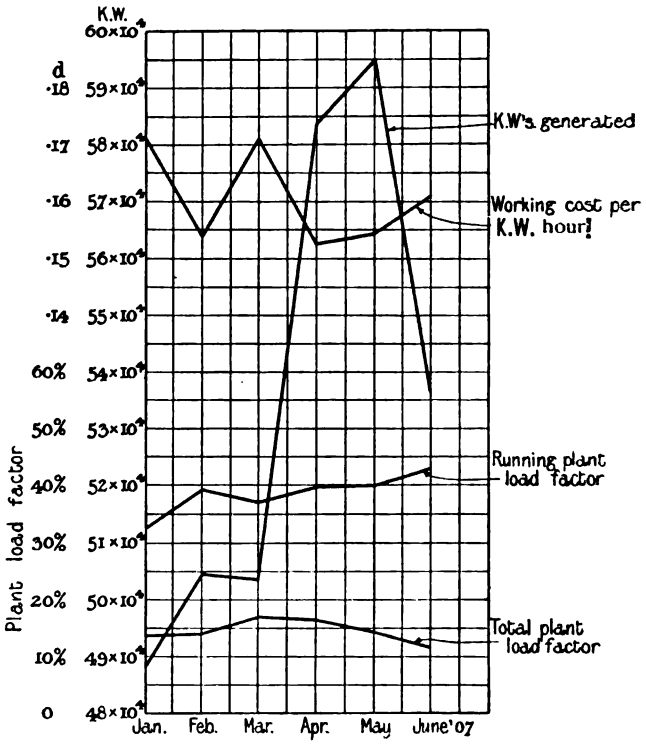


FIG. 1.

an overload capacity up to 920 H.P. Normal steam consumption, 5·6 kg. per horse-power-hour. Switching arrangements have been made wherewith the station can be worked in parallel with the Krughütte and Kupferkammer line.

The Lahmeyer Kupferkammer Generating Station.—Two of the three large units which this station will contain when completed are already running on a day and night load. The plant calls for special mention in so far as use is made of the blast furnace gas of the surrounding foundry for firing one of the two batteries of boilers of the station. Naturally this will not lead to such economy as is obtained with the

direct-driven engines at the Krughütte generating station. Direct driving, however, in this case would not have been practicable owing to the comparative low calorific value of the gases, namely, 400–450 calories per cubic metre. The average chemical combination of the available blast gas, expressed in volumetric per cent., is as follows:—

CO_2 ...	...	...	14·2	vol. per cent. per cubic metre.
C ...	...	...	0·12	,, ,,
CO ...	...	...	14·75	,, ,,
N ...	...	...	70·93	,, ,,

The dust and grit, etc., carried over by the furnace gas contains, as in the case of the Krughütte plant, a large percentage of lead; it is

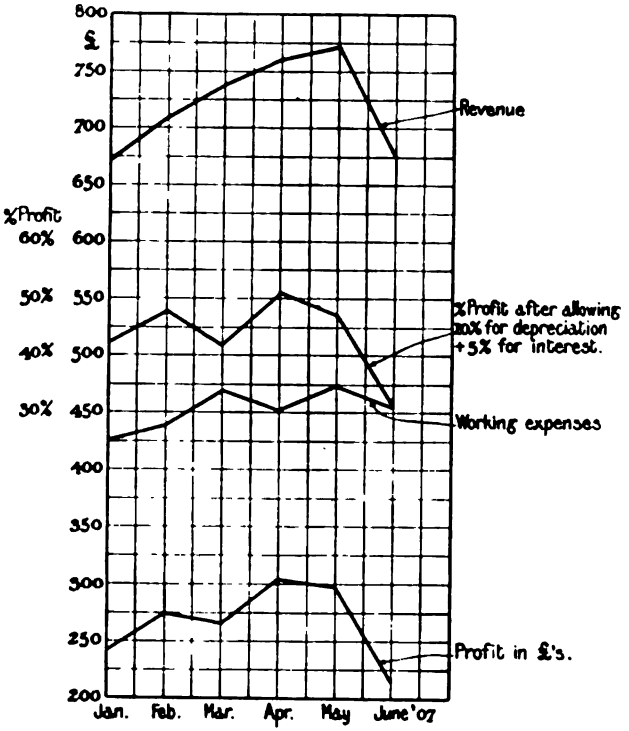


FIG. 2.

therefore, impracticable to blow out the deposit between the water tubes of the boiler by utilising, as is generally the case, the high-pressure steam of the boiler; this on account of an adhering substance which would be formed by the action of the steam on the lead deposit. The work is performed by an electrically-driven air compressor, delivering at a pressure of 8 atmospheres.

Each boiler is constructed with two water drums, 1,300 mm. in diameter, and 7,100 mm. in length, and contains 180 water tubes each 4,500 mm. in length, with an inside diameter of 114 mm. and an outside diameter of 117·75 mm. Grates, in which a small fire is continuously burnt, are provided for the purpose of igniting the blast furnace gas. The second battery consists of four ordinary coal-fired boilers, with mechanical stokers each of a heating surface of 300 square metres, and is worked, as in the case of the blast furnace gas boilers, at a pressure of 13 atmospheres. Each boiler is fitted with a superheater, having a heating surface of 60 square metres for raising the temperature of the steam 350° C. The economiser takes the form of a cylindrical vessel with circulating pipes, placed immediately between the steam exit of the low-pressure cylinder and the condenser. The steam delivery, as well as the water-feeding pipes, are laid in duplicate so as to minimise the risk of a shut-down in the station.

The station was originally projected for an output of 2,000 k.w.; this has, however, now been increased to 5,000 k.w. The two first units to be put down comprise two Lahmeyer high-tension flywheel alternators, each capable of an output of 1,250 kilovolt-amperes at a power factor of 0·8 at 10,500 volts 50 ∿ running at a speed of 107 revs. per minute. The mass of each rotor is such that with a varying load and with the engine exhausting either direct or through its condenser, the variation of the speed during 1 revolution is not more than 1 : 250.

Each generator is driven by a tandem triple-expansion engine built to the Lahmeyer specification by the Hannover'sche Maschinenbau Actien-Gesellschaft, having a normal output of 1,500 H.P. with an overload capacity of 1,800 H.P. The diameter of the high-pressure cylinder is 620 mm., the medium pressure 970 mm., and the low-pressure cylinders 2 × 1,100 mm. Length of stroke, 1,300 mm. Each engine is controlled with Lentz's patent precision valve regulator, which is so set as to allow a speed variation during running of 5 per cent.

The cooling water used in connection with the jet condensers is carried up to a cooling tower by means of two centrifugal pumps, each with an output of 440 cubic metres per hour when working against a head of 10 metres. These pumps are driven by two Lahmeyer 3-phase 30-H.P. 500-volt motors running at 750 revs. per minute.

The main switchboard, which is situated at one end of the station, comprises 13 panels. Only instruments and controlling apparatus are mounted on the board, all high-tension apparatus being placed, as usual, in a separate chamber. The oil switches of the main generators are worked from the low-tension switchboard by means of light steel shafting, and each is provided with an automatic release actuated by an overload time limit relay and signal lamp contacts. The high-tension switchgear and busbars are mounted in a chamber built parallel to the switchboard gallery, but on the ground floor. In this chamber are mounted the oil switches for connecting the various feeding cables and transformers to the 10,000- and 3,000-volt ring busbars. The busbars

are provided with sectionalising links so as to enable any faulty generator, transformer, or cable section to be cut out without interrupting the supply of current to the other sections. Each of the 26 high-tension panels is complete in itself, being provided with an overload release, time relay, signal lamp, and releasing circuit, this latter being actuated by a button from the low main tension switchboard.

The transforming plant consists of the following Lahmeyer oil-cooled transformers :—

4	200 k.v.a.	10,000/3,000 volts	50 ∼.	
2	150 „	10,000/500	„	„
4	·75 „	10,000/500	„	„

The excitation current of the main generators is provided by means of two single and one double 3-phase continuous-current motor-generators. The double aggregate consists of two continuous-current dynamos mounted one on either end of the shaft with the 3-phase driving motor mounted in the middle.

The outputs are as follows :—

3-phase motor : 175 B.H.P., 500 volts, 750/730 revs. per minute, 50 ∼

Continuous-current dynamos : each 55 k.w., 220 volts.

The single set comprises a 3-phase 85-B.H.P. 500-volt motor directly coupled to a 50-k.w. 220-volt continuous-current dynamo. In addition to these sets, which work in parallel on the same busbars, a small booster for 30/100 volts, driven by a 3-phase squirrel-cage motor, is provided for charging, in conjunction with the continuous-current sets, the station battery. This consists of 126 cells with a capacity of 185 ampere-hours. This battery is used for driving the 6-H.P. barring motors, for running the small-air compressor, used for cleaning the tubes of the blast gas-fired boiler, and also for lighting purposes in cases of emergency. This station has now been at work for about two months, and up to the present has given every satisfaction.

Distributing System.—A great deal of care and thought was given to the arrangement of the distributing system in order to minimise as far as possible the risk of breakdowns. The cables have in almost all cases been laid in pairs.

Underground cables were chosen in preference to overhead lines, as the routes pass through a great number of villages and along high-roads, so that for a 10,000-volt system very elaborate safety guards would have been required. A further consideration was the avoidance of disturbances caused by the very frequent severe local thunder-storms. Also the cables are not subject to the deteriorating effects of the atmosphere, impregnated with sulphur fumes from the surrounding foundries.

The original distributing system, at the time the Krughütte central station was put to work (two years ago), consisted chiefly of a 3,000-volt

ring trunk main. Starting from the Krughütte, the cable passes by way of the Clotilda pit to the Oberhütte and Hohenthal pit, and then back over the Ernst, Martin, and Wimmelburg pits to the Krughütte station. The distances, including an allowance for differences of level, are approximately as follows :—

Central station to Clotilda pit	1·9	km.
Clotilda pit to Oberhütte	1·9	,,
Oberhütte to Hohenthal	2·2	,,
Hohenthal to Ernst pit	2·9	,,
Ernst to Kochhütte...	0·95	,,
Kochhütte to central station	4·1	,,
	13·95	km. (8 miles)

The cable is of the 3-core paper-insulated type, cross-section of the copper of each core is 0·077 sq. in.

The cables running from the central station at Krughütte to the actual Krughütte smelting works, the Otto and Hermann pits, have been placed outside the actual ring, principally on account of the blowers for supplying the forced draught to the furnaces at the Krughütte, and on account of the electric main winding engine at the Hermann pit. This plant is working continuously day and night, with the result that later on difficulties would have been experienced when extending the cable system.

Owing to the comparatively long distance between the Krughütte and Kupferkammer works, it was deemed advisable when laying down the new central station at the Kupferkammer to generate direct at 10,000 volts. In order, however, to allow of the new station being worked in parallel with the central stations erected at the Hohenthal pit and Krughütte works, a small sub-station has been erected at the Oberhütte. This contains a 420-kilovolt-ampere oil-cooled transformer of the Lahmeyer type, transforming the 10,000-volt pressure down to the 3,000 volt, which, as before mentioned, is the generating voltage of the Krughütte and the Hohenthal stations. A system of 10,000-volt cable is laid between the Kupferkammer works and Oberhütte, passing through two busbar switch houses erected in the neighbourhood of the Niewandt and Zirkel pits. From the former 10,000-volt 3-core paper-insulated cables are run to the Niewandt and Paul pits, while from the latter similar cables are taken to the Zirkel and Vitztum pits. The Zirkel switch house receives energy from both sides of the system —namely, from Kupferkammer, Krughütte, and Hohenthal stations, the risk of a breakdown, therefore, is considerably lessened.

Separate cables are run from the Kupferkammer station to the surrounding foundry, and to the Bessemer, Saiger, and Gottesbelohnung works. These are under a pressure of 3,000 volts (1·5 sq. mm.). Having dealt with the generating and distributing system, attention may now be turned to the secondary plant installed at the various pits and foundries of the Company.

Electrical Equipment of the Krughütte Copper Works.—The principal electrical plant at the Krughütte foundry consists of the 3-phase motors driving the blowers and feeding mechanism of the blast furnaces, the aerial wire ropeway conveying ore direct from the Hermann pit to the furnaces, and the smaller motors for driving the moulding machines and the pumps for the water-cooling of the furnaces.

The 3,000-volt induction motors driving the Jaeger rotary blowers for supplying the forced draught to the furnaces are kept running day and night. These blowers are of extremely simple construction, and are entirely without valves. As the revolving parts do not come into actual contact, the efficiency is comparatively high, being approximately 75 per cent. Each blower is designed for an output of 250 cubic metres of free air per minute at a pressure of 100 mm. of mercury. They run at a speed of 250 revs. per minute, and each is driven by belting from a 125-H.P. motor running at 750 revs. per minute on the 3,000-volt 50-∿ 3-phase circuit.

Two electrically-driven centrifugal pumps, each with an output of 75 metres per minute, are provided for circulating the water for the cooling of the furnaces. Each is driven by ½-H.P. 500-volt induction motor. Moulding machines are used for compressing the small or dust ore into moderate-sized bricks, which are afterwards fed in the furnaces. These are belt-driven by 10-H.P. 500-volt 3-phase motors. The workshops are equipped with 3-phase asynchronous 500-volt motors. The feeding mechanism of the furnaces is driven through chain transmission by 3-phase motors. The gear for each furnace is capable of dealing with 3,000 550-kg. wagons per twenty-four hours.

The aerial steam ropeway between the Hermann pit and the furnaces of the Krughütte is 7 kilometres in length. The driving power is derived from a 10-H.P. 3-phase 500-volt motor. A second motor has been erected as a reserve. The average cost of transportation per kilometre-ton with this line works out to about 2½d. Average monthly transportation, 5,500 tons.

Electrical Equipment at the Kupferkammer Smelting Works.—From the 10,000-volt ring busbars at the Kupferkammer station four feeding cables are run over the Niewandt and Gottesbelohnung pits to the busbars of the Zirkel pit switch house, which, as before mentioned, is coupled up over the Oberhütte transforming sub-station to the Krughütte power house. Spark-gaps are used for protecting the outgoing 10,000-volt cables, the lead sheathing of which, as well as the steel armouring, are electrically connected throughout their entire length.

From the 3,000-volt ring busbars feeding cables are run to the neighbouring smelting and Bessemer works. The principal plant here consists of three Lahmeyer 125-H.P. 3,000-volt motors for driving the blowers of the Kupferkammer blast furnaces. Fourteen 22-B.H.P. 550-volt, and six 10-B.H.P. 550-volt motors are used for driving pumps, moulding and sifting machines, and for the various workshops. At the same time cables are run from the same 3,000-volt bars to the

Gottesbelohnung works, where 3-phase current is used for driving the furnace blowers, the grinding and rolling machines, the workshops, and for lighting purposes.

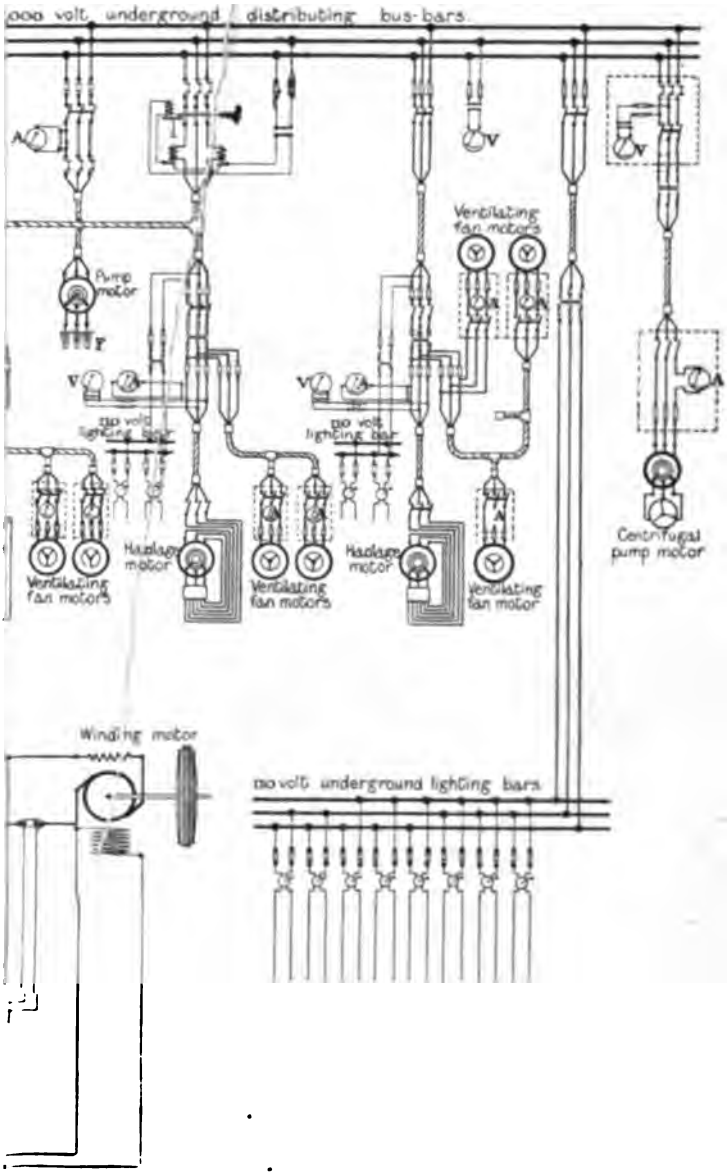
Electrical Equipment at the Hermann Pit.—A complete diagram of connections of the installation at the Hermann pit is given in Fig. 3. This forms the most interesting part of the equipment of the group of mines, including, as it does, an electrical main shaft winding plant. Power is obtained from the Krughütte central station, over two 3,000-volt 3-phase underground cables, each with a cross-section of 75 sq. mm. The 3-phase motors replacing the steam-driven ventilators, winches, centrifugal pumps, workshop tools, and the continuous-current dynamos for lighting require no special mention, being of the ordinary Siemens-Schuckert 3-phase induction type, with liquid starters. The winding plant is on the well-known Siemens-Ilgner system, in which a motor-generator, provided with a heavy flywheel, is used for equalising the load, and the control of the continuous-current winding motor is effected by variations of the excitation of the continuous-current generator forming part of the flywheel set.

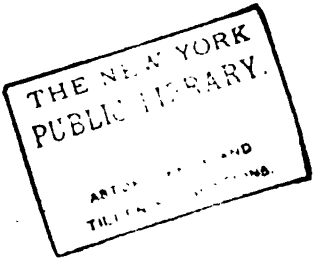
The advantages of this method of control, which is a modification of the Ward-Leonard system for this class of work, lie not only in the good efficiencies obtainable at all speeds, but in the fact that "regenerative-making" may be taken advantage of and power returned to the flywheel set. The speed of the winding motor corresponds definitely to the position of the control lever, and an acceleration or braking effect is produced according as the lever is moved from a position corresponding to a higher or lower speed, and is independent of the amount of load on the machine, or whether the cage is ascending or descending.

The controlling apparatus itself is only required to carry the relatively small excitation current of the generator, which is not more than 2 to 3 per cent. of its output. The arrangement of connections of the winding gear is clearly shown in Fig. 3.

The speed of the motor-generator varies from about 12 per cent. to 15 per cent., as the rotating masses absorb or give out power; and to enable the 3-phase motor to absorb practically constant current from the line an automatic regulator actuated by relays is used, which cuts resistances in and out of the rotor circuit as required.

The general particulars of the winding plant at the Hermann pit are as follows: Output, 760 tons per 8 hours' shift; depth, 366 yards, to be extended later to 633 yards; number of trucks per cage, 4; effective load, 4,930 lbs.; maximum rope speed, 1,180 ft. per minute, to be increased later to 2,340 ft. per minute. A Koepe pulley, 16 ft. 6 in. diameter, is used with a rope 1·5 in. in diameter. The flywheel set is driven by a 3-phase 3,000-volt induction motor, rated at 320/292 H.P., and running at a maximum speed of 493 revs. per minute. The continuous-current generator is wound for a maximum voltage of 400 volts and an output of 1,440 amperes. The winding motor can work up to


000 volt underground distributing bus-bars.
A
V
Pump motor
V
V
110 volt lighting bars
110 volt lighting bars
Ventilating fan motors
Haulage motor
Ventilating fan motors
Haulage motor
Ventilating fan motor
Ventilating fan motors
Centrifugal pump motor
Winding motor
110 volt underground lighting bars.


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665 B.H.P. at 400 volts at a speed of 38·5 revs. per minute. The total energy stored in the flywheel is 140,000 metre kilogrammes, which is more than enough to complete the wind should the current supply fail. The set has been at work since April, 1905.

An important item of the equipment is the depth indicator, with which is combined a safety gear. The principle of the safety apparatus consists in the use of a cam-wheel, the movement of which is synchronous with that of the indicator, and which controls automatically the position of the control lever, and consequently the speed of the cage, during the whole time of the wind. This cam is composed of two discs mounted upon the same shaft, each corresponding to one direction of working. Their speed of rotation is such that they make one complete revolution per wind. The control lever is connected to rollers which press against the profile of the cams when the driver moves the lever. The variations in the profile of the cams limit the distance through which the driver can move his lever, according to the position of the cage in the shaft. At the beginning of the wind the driver moves his lever in the required direction, but without being able to pass the position fixed by the corresponding cam. The winder starts and attains the speed corresponding to this position, the cam-wheel rotates simultaneously, and allows of the lever being further advanced, so that the speed is increased, and so on, until the maximum is reached. The form of the cam thus determines the rate of acceleration. The driver is always able to draw back his lever for reducing the speed. If he forgets to do this at the right time towards the end of the wind, the lever is returned automatically by the cam, and the speed of the winder is retarded at a prescribed rate. The cam is of such a form that at the part corresponding to the end of the wind it returns the control lever automatically so far back that the speed falls to quite a small value, but from this instant the profile is concentric with the axis of the disc, so that the driver is able to use this slow speed in the neighbourhood of the pit bank for the purpose of carrying out the necessary banking operation at low speed up to the moment when the cage passes the bank. At this instant the profile of the cam makes an abrupt change and rapidly returns the control lever to the "off" position. At the same time a stop works upon an unlocking gear at the end of the run, which immediately puts on the safety brake, and the winding engine, which has already been slowed down, is brought entirely to rest. It is thus seen that the safety apparatus compels the driver at each wind to adhere, whatever the load, to the rate of working which has been prescribed. It in no way interferes with the driver so long as he operates the levers correctly, but in every case resists an attempt to move them wrongly. The absolute security ensured by this apparatus has been recognised by the Inspection Commission for winding men, in the mining district of Dortmund, who have given permission for the speed of winding to be raised from 6 metres per second, the maximum hitherto allowed, to 10 metres per second when winding men.

The actual working results obtained at the Hermann pit over the

TABLE II.

The Working Results obtained with the Eectrically-driven Main Winding Gear at Hermann Pit.

Month (Year, 1907).	Journeys.	Shifts, at 8 Hours	Output in Tons.	Depth in Metres.	Total Output in Kilometre-tons.	Total Horse-power Seconds.	Eelectrical Units Consumed.			The Electrical Cost.	
							Total Kilowatts.	Per H.P.-hour.	Per Kilometre-ton.	Per H.P.-hour.	Per Kilometre-ton.
										d.	d.
January ...	17,529	52	35,229	330	11,625·57	103,050	76,865	1,793	6·61	0·62	2·3
February ...	19,141	48	37,715	330	12,446·19	120,044	77,390	1,678	6·26	0·58	2·2
March ...	18,831	50	38,439	330	11,531·94	106,777	68,838	1,011	6·01	0·56	2·1
April... ...	19,254	50	38,568	330	12,727·44	117,846	69,610	1,476	5·51	0·51	1·9
May	17,986	50	36,417	330	12,017·54	111,273	61,047	1,371	5·12	0·48	1·7
June	—	—	—	—	—	—	—	—	—	—	—

Diameter of Koepe pulley 5 metres.
„ rope wheel 5 „
„ steel rope 44 millimetres.
Weight of cage 4,260 kilogrammes.
Carrying capacity 4 wagons, at 550 kilogrammes.

first six months of last year are given in curves in Figs. 4 and 5 and in Table II., which show the electrical costs per B.H.P.-hour at per kilometre-ton. These are compared with the costs of steam winding at the Niewandt and Zirkel pits under similar circumstances. These curves, obtained from actual data, are very valuable in illustrating the increased economy obtainable by the substitution of electricity for steam for main shaft winding. It must be borne in mind that the cost given in both cases is for the value of the actual energy consumed, and

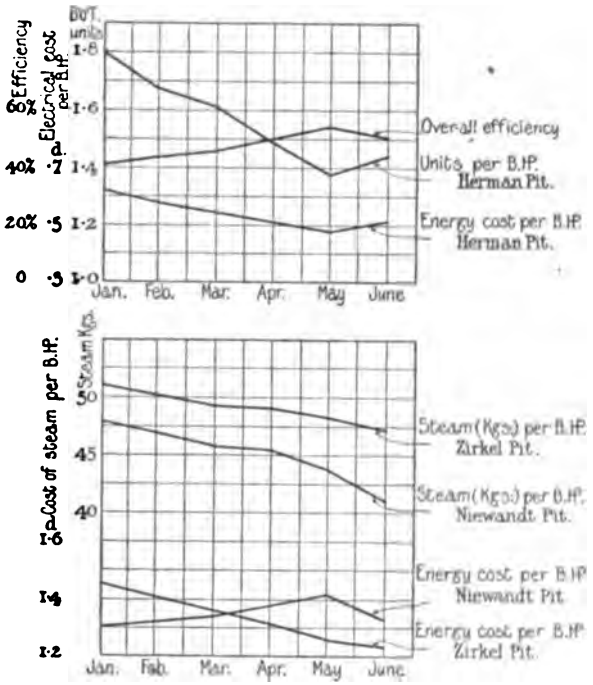


FIG. 4.—Hermann, Zirkel, and Niewandt Electrical and Steam-winding Pits.

does not in either case cover incidental expenses incurred during the six months.

A second shaft is at present being sunk, and for this purpose a 150-H.P. Lahmeyer 500-volt 3-phase motor has been erected for the working of a temporary cage.

The Zirkel Pit.—The second electrically equipped mine of importance is the Zirkel pit. This pit lies outside the actual cable ring, and obtains its current from 3-core cables tapping the 10,000-volt busbars in the switch house, referred to already, which is connected to both the Krughütte and Kupferkammer stations. Oil cooled transformers at the

pit mouth transform the incoming 10,000 volts down to the working pressure of 3,000 volts. At this pressure the current is taken down the shaft of the pit, a distance of over 2,200 ft., by means of a 3-core cable of 35 sq. mm. (0·077 cross-section). At the fifth, and at present lowest, seam there is another Lahmeyer transformer, which further reduces the pressure of one circuit to 500 volts. With this pressure the four 3-phase star-connected 30-B.H.P. Lahmeyer motors for working underground roadways are driven.

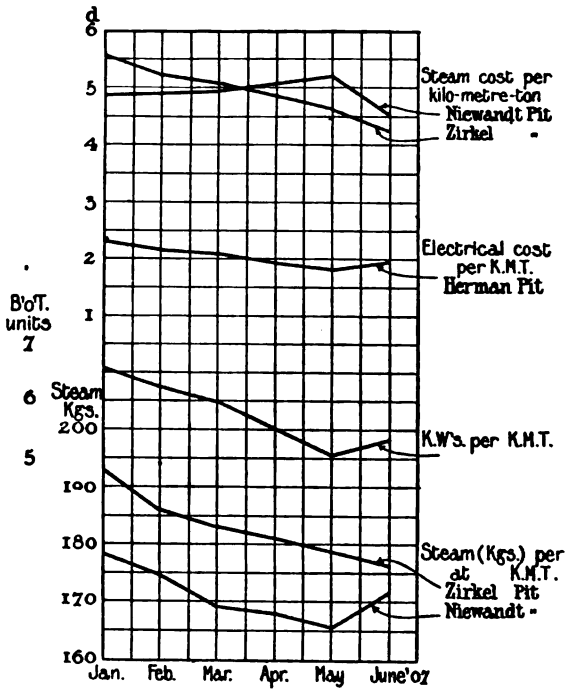


FIG. 5.—Hermann, Zirkel, and Niewandt Pits, Electric and Steam Winding.

The working results of the longest roadway (approximately 1,100 yards) are shown in the form of curves in Fig. 6 and in Table III. in comparison with the cost per kilometre-ton for the last six months of working with the original compressed-air plant. The economy effected by the electrification of these roadways is clearly shown. The capital outlay in this case was not very high, as no radical change had to be made in the actual endless chain-driving machine and gear. The motors and driving machines are geared with a ratio of 1 : 16.

The output of the largest ventilating fan in the Zirkel pit, which is used for circulating air in the fourth seam, has an output of 4,000 cubic

TABLE III.

The Working Results of the Electrically-driven Underground Roadway in the Zirkel Pit.

Month (Year, 1907).	Wagons Forwarded. Weight, 550 Kgs.	Working Shifts of 8 Hours.	Length of Roadway in Metres.	Output in Kilometre-tons.	Electrical Units Consumed.		Eletrical Cost per Kilometre-ton.
					Total.	Per Kilometre-ton.	
							d.
January	Not	finished.	—	—	—	—	—
February	5,580	46·25	1,000	3,069·0	1,237	0·41	0·14
March	9,230	75·50	1,000	5,076·5	2,876	0·57	0·19
April	10,720	82·00	1,000	5,896·0	2,320	0·39	0·13
May	11,610	85·50	1,000	6,385·5	2,888	0·45	0·16
June	—	—	—	—	—	—	—

metres per minute when working against a pressure of 100 mm. of water. The diameter of the blades is 10 ft. This fan is driven through a belt by means of a 3,000-volt 185-B.H.P. 3-phase Lahmeyer motor at a speed of 600 revs. per minute. In the same machine-room is erected a 30-B.H.P. 500-volt 3-phase Lahmeyer motor for driving a centrifugal pump used for pumping the incoming water up to the storage tanks placed overbank at the surface. There are also three small ventilators of the Rateau type driven by 30-H.P. 500-volt 3-phase motors.

The motors for the sawmill, workshops, etc., at the surface are worked at a pressure of 500 volts. A third oil transformer, with an output of 100-kilovolt amperes, has been erected for this purpose in the pit, transforming the 10,000 volts down to 500 volts for the motors and

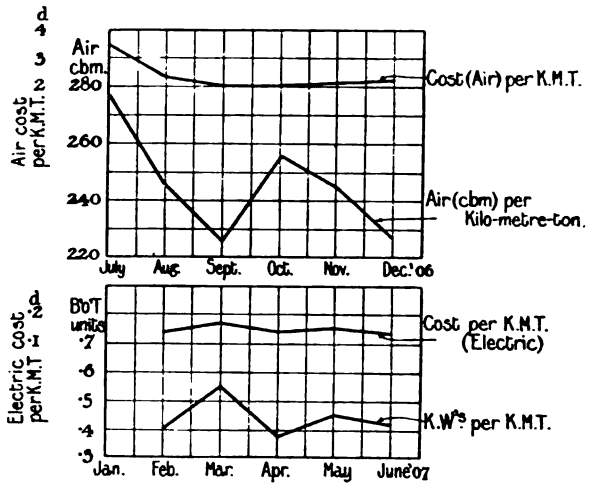


FIG. 6.—Electric and Zirkel Pit Steam-Air Hauling in Underground Roadway.

to 100 volts for lighting purposes. The working costs and steam consumptions per B.H.P. and kilometre-ton are shown in Figs. 4 and 5 and Table IV. in comparison with the cost for electrical winding at the Hermann pit.

Hohenthal Pit.—Current for the supply to this pit can be taken either from own generating plant or from the ring main.

The first move at the Hohenthal pit was the electrification of the underground roadways, which until recently were driven by compressed air supplied from a steam-driven compressor. The cost of this method of working is very high, amounting to approximately 3·8d. per B.H.P. against 0·87d. when driven electrically. The electrification has been carried out by using the flywheel of the air engine as the belt-driven pulley of the 3-phase 100-B.H.P. 3,000-volt motor. In all other respects the engine remains unchanged, with the result that the

TABLE IV.

The Working Results obtained with the Steam-driven Main Winding Gear at Zirkel Pit.

Month (Year, 1907).	Journeys	Shifts at 8 Hours	Output in Tons. (1,000 Kg.)	Depth in Metres.	Total Output in Kilometre-tons	Total Horse-power Seconds.	Steam Consumption.			Steam Cost.		
							Total Kilogrammes.	Per H.P.-hour.	Per Km.-ton	Per 1,000 Kg.	Per H.P.-hour.	Per Km. ton.
								Kg.	Kg.	s. d.	d.	d.
January	16,879	77	35,093	395	13,861·85	83·34	2,668,575	51·34	193·4	2 8	1·45	5·5
February ...	—	71	34,033	395	13,443·35	87·66	2,489,575	50·00	185·9	2 8	1·40	5·2
March	—	71	35,623	395	14,071·36	87·55	2,562,000	49·16	183·8	2 7	1·36	5·1
April	17,044	74	35,418	395	13,990·30	83·93	2,542,000	49·00	182·1	2 6	1·30	4·8
May	15,694	71	32,587	395	12,871·90	94·70	2,295,200	48·14	179·1	2 6	1·25	4·6
June	—	—	—	—	—	—	—	—	—	—	—	—

Diameter of high-pressure cylinder	0,82 metres.
„ low-pressure „	1,152 „
Length of stroke	1·6 „
Diameter of winding drum	5·6 + 6·6 „
„ rope wheel	5·0 „
„ steel rope	38·5 millimetres.
Weight of cage	2,665 kilogrammes.
Carrying capacity	4 wagons, at 550 kilogrammes.

roadways can still be driven with the air engine should the necessity arise. The underground ventilators, which were also steam-driven, have now been coupled up to two 10-B.H.P. 500-volt 3-phase motors. The boring machines, as well as the workshops at the surface, are also electrically driven.

There was every cause to believe that an inrush of water would shortly take place in this pit, and for this reason a complete 3-phase generating plant had been erected for supplying power to the electrically-driven pumps, which are now being erected at a depth of approximately 2,000 ft. The dimensions of the underground pump-room are 32 × 10 × 8 metres, and it contains two pumping sets, each consisting of a twin cylinder plunger pump, with the rotor of its motor mounted on the shaft between the two cranks. The output of each pump is 15 cubic metres per minute when working against a head of 160 metres. The 3-phase motors are of Messrs. Siemens Schuckert's standard type, each designed for a continuous output of 650 B.H.P., and they run at a speed of 90 revs. per minute on the 3,000-volt 50-∿ circuit.

The above-mentioned "inrush of water" came, but unfortunately not in the place where it was expected, as there is no connection between the Hohenthal and Zirkel pits except through the fourth seam. Should the water rise to the height of 300 ft.—and this is probable —then the pumping station at this pit, with its total output of 45,000 litres per minute, can be made use of.

The Vitzum and Paul Pits.—At these pits, both of which are still in the process of being sunk, current is now being used for sinking operations and for hauling purposes. The complete plant when finished will be electrically driven upon the same principle as the Hermann pit.

The Niewandt and Edward Pits.—No great change in the method of working is to be expected at these pits, as both will be completely worked out in the course of a few years. Three-phase current, however, is used for driving the workshop motors and continuous current for lighting purposes.

In conclusion, the author's thanks are expressed to the directors of the Mansfeld Copper Mining Company for permission to describe the detailed working of their undertaking and for having kindly given him access to all the pits and works of the Company.

ELECTRICITY AND MATTER, WITH SOME ACCOUNT OF RADIATIONS.

By LAURENCE H. A. CARR, B.Sc.Tech., Student.

(*Paper read before the* STUDENTS' SECTION *at Manchester, December 17, 1907.*)

As members of a scientific Institution, such as this is, and as scientific men, all new discoveries with regard to the fundamental theories of matter—from the phenomena associated with which we deduce our sciences—must be of great importance to us.

And this importance is increased when we recollect that this new theory which has arisen not only gives us a fresh idea of the constitution of matter, but also of electricity, and forms a new foundation for the science which we profess, yet not weakening the old basis, but rather reinforcing it.

The old idea of a molecule was and is still correct—"the smallest weight of matter in which the original properties of the matter are retained." A molecule is composed of a combination of the atoms of its constituent elements. This is text-book chemistry that is well known. But the new theory states that the atoms are not absolutely ultimate and indivisible. Certainly an atom of hydrogen is the smallest particle of hydrogen that can exist (either in the free or combined state) as hydrogen, but it is built up of smaller non-hydrogenic particles. These ultra-atomic particles are called by various names. I here use the term "corpuscles," as the word "electrons," which is often used, is applied rather loosely by some people to various sub-atomic combinations.

An atom, as we conceive it to be, is built up of a number of separate corpuscles, and is thus granular in character. The number of corpuscles seems to be approximately 2,000 per unit of atomic weight. Thus the atom of hydrogen contains about 2,000 corpuscles, that of oxygen about 32,000, and so on. And, so far as we know, the corpuscles out of which a hydrogen atom is built up are identically the same as the corpuscles out of which an oxygen atom is built up. This is not all however. These corpuscles are particles of negative electricity.

Now it is generally considered that a current flows from the positive to the negative pole of a dynamo *vid* the external circuit; but this is wrong. The current really moves in the other direction—that is to say, negative electricity is the electricity. An electric current is thus the passage of a number of small granules of electricity (I use the word

"granules" for want of a better term), so that the old idea of electricity as being material is not so far wrong, though the particles are not material, but rather ultra-material. And the corpuscles that go to build up an atom are exactly the same as the corpuscles that, moving, form an electric current.

These corpuscles alone, however, do not constitute the atom. In addition to them there is a so-called sphere of positive electricity or electrification, the exact nature of which is unknown, which just balances the electrical charge of the negative corpuscles so that the

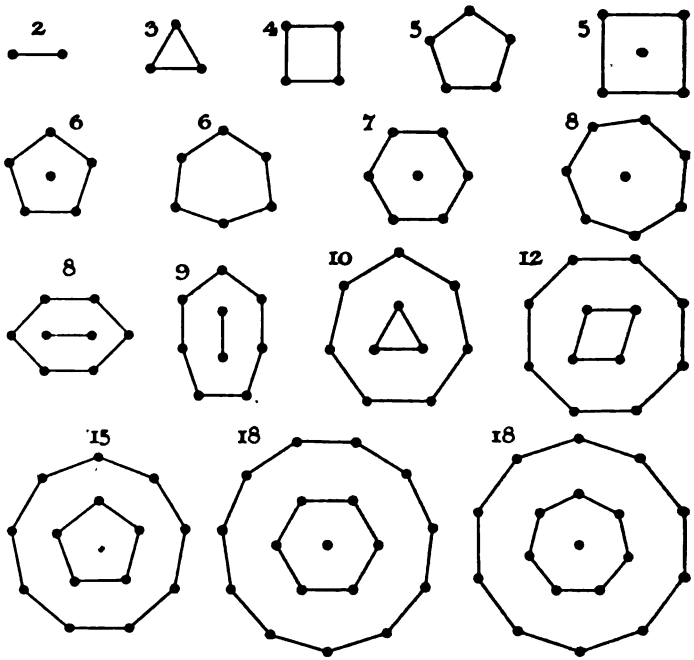


FIG. 1.

atom as a whole is neutral. This sphere of positive electricity binds the corpuscles together, as otherwise they would, of course, repel each other and scatter.

The atom is thus complete in itself (except under conditions to be stated later) and does not tend to change in any way, no outside mechanical force breaks it up, and only certain electrical (or chemical) forces affect it. It is thus somewhat similar to the constitution of the molecule, although built of smaller particles, which similarly does not change except under special conditions.

It is essential to get a clear idea of this constitution of the atom. The best illustration known is J. J. Thomson's now classical experi-

ments with floating magnets. Only it must be remembered that the atom exists in 3 dimensions, while the experiments to be described are only in 2 dimensions.

Thomson employed a number of magnets fixed in cork and weighted so as to float vertically, all similar poles pointing upwards. The sphere

TABLE I.

Magnet Systems or Model Atoms.

Number of Magnets.	61	41	25	12	3
Number in successive rings ...	20	16	13	9	3
	16	13	9	3	—
	13	9	3	—	—
	9	3	—	—	—
	3	—	—	—	—

of positive electrification was represented by a large pole of opposite sign suspended above the water.

Experiments were tried with numbers of magnets from two upwards, and it was found that, when allowed to settle, these magnets came into certain definite positions with regard to each other (Fig. 1).

Up to a certain number these floating magnets form one ring; then they form two sets or rings; then again, as the number is increased, they

TABLE II.

The First Table of the Periodic Law.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1	H 1	—	—	—	—	—	—	—
2	L 7	Be 9	B 11	C 12	N 14	O 16	Fl 19	—
3	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35·5	—
4	K 39	Ca 40	—	Ti 48	V 51	Cr 52	Mn 55	Fe 56 Co 59 Ni 59

form three rings, and so on. We can thus obtain a group, each member of which is formed from the preceding one by the addition of a fresh ring of magnets (or corpuscles which they represent)—Table I.

TABLE III.

The Periodic Law.

Series.	Group 0.	Group I.	Group II.	Group III.	Group IV.	Group V.	Group VI.	Group VII.	Group VIII.		
0	—	—	—	—	—	—	—	—	—		
1	—	Hydrogen H = 1·008	—	—	—	—	—	—	—		
2	Helium He = 4·0	Lithium Li = 7·03	Beryllium Be = 9·1	Boron B = 11·0	Carbon C = 12·0	Nitrogen N = 14·04	Oxygen O = 16·0	Fluorine Fl = 19·0	—		
3	Neon Ne = 19·9	Sodium Na = 23·05	Magnesium Mg = 24·1	Aluminium Al = 27·0	Silicon Si = 28·4	Phosphorus P = 31·0	Sulphur S = 32·06	Chlorine Cl = 35·45	—		
4	Argon Ar = 38·0	Potassium K = 39·1	Calcium Ca = 40·1	Scandium Sc = 44·1	Titanium Ti = 48·1	Vanadium V = 51·4	Chromium Cr = 52·1	Manganese Mn = 55·0	Iron Fe = 55·9	Cobalt Co = 59·0	Nickel Ni = 59·0
5	—	Copper Cu = 63·6	Zinc Zn = 65·4	Gallium Ga = 70·0	Germanium Ge = 72·3	Arsenic As = 75·0	Selenium Se = 79·0	Bromine Br = 79·95	—		
6	Krypton Kr = 81·8	Rubidium Rb = 85·4	Strontium Sr = 87·6	Yttrium Y = 89·0	Zirconium Zr = 90·6	Niobium Nb = 94·0	Molybdenum Mo = 96·0	—	Ruthenium Ru = 101·7	Rhodium Rh = 103·0	Palladium Pd = 106·5
7	—	Silver Ag = 107·9	Cadmium Cd = 112·4	Indium In = 114·0	Tin Sn = 119·0	Antimony Sb = 120·0	Tellurium Te = 127·0	Iodine I = 127·0	—		
8	Xenon Xe = 128·0	Cæsium Cs = 132·9	Barium Ba = 137·4	Lanthanum La = 139·0	Cerium Ce = 140·0	—	—	—	—		
9	—	—	—	—	—	—	—	—	—		
10	—	—	—	Itterbium Ib = 173·0	—	Tantalum Ta = 183·0	Tungsten W = 184·0	—	Osmium Os = 191·0	Iridium Ir = 193·0	Platinum Pt = 194·9
11	—	Gold Au = 197·2	Mercury Hg = 200·0	Thallium Tl = 204·1	Lead Pb = 206·9	Bismuth Bi = 208·0	—	—	-		
12	—	-	Radium Ra = 224·0	-	Thorium Th = 232·0	-	Uranium U = 239·0		—		

Now these represent, on a small and simplified scale, atoms (of course, these models are plane atoms, not 3-dimensioned ones such as really exist). The atomic weight of these atoms in this model universe we are imagining would be 61, 41, 25, 12, 3.

Now let us turn for a while to Mendeléeff's periodic law. Table II. shows the table of the law as first laid down by Mendeléeff, showing but 24 of the elements in their positions.

Table III. shows the latest table as drawn up by Mendeléeff in 1904, some few elements as terbium (160), thulium (171), and other rare elements being omitted, as the correct space they should occupy is as yet undetermined.

Now several relationships are expressed in this law.

First, it indicates that elements in the same vertical column have to a large extent similar properties. This is, no doubt, well known ; for example, the halogen family, which are all in column VII. of the table, have many properties in common which increase or decrease in intensity as their atomic weight increases (such, for example, as boiling-point, solubilities, combining powers, etc.).

Now, in our model atom these elements correspond to such a series

TABLE IV.

Dobereiner's Triads.

(Atomic Weights.)

Chlorine	...	35·4	Model Element	A	...	61
Iodine ...	...	126·8	„	C	...	25
		2)162·2				2)86
		81·1				43
Bromine	...	80·0	„	B	=	41

as 61, 41, 25 before mentioned, each of which is a replica of the last, with an additional ring around it.

This, at any rate, points to an explanation of these recurring phenomena. For if a bromine atom is exactly the same as a chlorine atom, with an extra spherical layer (or layers) of corpuscles, then it is natural for the properties of the two to be greatly similar.

Another relation often mentioned in chemical text-books is the Triads of Dobereiner (Table IV.).

Thus, if three similar elements—chlorine, bromine, and iodine—be taken, the arithmetical mean of the atomic weights of the extremes is just a little greater than the atomic weight of the intermediate element.

This similarity between the two calculations when the mean of the two outer elements is not quite equal to, but is a little greater than the atomic weight of the intermediate element, is very striking. And this is equally true if we take other chemical triads, as calcium, strontium, and barium, or sulphur, selenium, and tellurium, and also for

other sets of numbers representing model atoms, these numbers being experimentally obtained by the method above outlined.

It cannot be too strongly pointed out that before this theory came into existence it was realised that: "The properties of the elements, as well as the properties of their compounds, form a periodic function of the atomic weights of the elements."

I quote the above sentence word for word from Newth's *Inorganic Chemistry*, published in 1899, before radium and its properties were discovered.

Now another property of this periodic law is that it divides the elements off into groups of valency (Table V.).

TABLE V.

Valencies.

Group.	0	1	2	3	4	5	6	7
Oxygen compound	None	R_2O	R_2O_2	R_2O_3	R_2O_4	R_2O_5	R_2O_6	R_2O_7
Hydrogen compound	None	—	—	—	RH_4	RH_3	RH_2	RH
Chlorine compound	None	RCl	RCl_2	RCl_3	RCl_4	—	—	—

There are many exceptions to this rule; still it holds sufficiently to be remarkable, and is pointed out in all elementary chemical text-books. Now, let us see what our model atoms can show us on the subject.

The series shown in Table VI. give all the configurations that can have an outer ring of 20 magnets. The total number of magnets in the configuration is from 59 to 67.

TABLE VI.

Series of Model Atoms with Outer Ring of 20.

Total Number of Magnets.	59	60	61	62	63	64	65	66	67
Number in successive rings	20	20	20	20	20	20	20	20	20
	16	16	16	17	17	17	17	17	17
	13	13	13	13	13	13	14	14	15
	8	8	9	9	10	10	10	10	10
	2	3	3	3	3	4	4	5	5

This we may take to represent a series across the table of the law.

Now element 59 is very unstable, while 67 is the most stable. Element 59 will easily lose one corpuscle, when it will acquire a positive charge, as the positive electricity it previously possessed was just enough to balance the 59 corpuscles.

Note that it would not then form an atom of element 58, as element 58 has only enough positive electricity to balance 58 corpuscles, not 59.

Element 60 would less easily lose a corpuscle and so on across the table, while at the other side element 67 is so stable that it would not only with great difficulty lose a corpuscle, but it could actually gain one

The case of 59 is peculiar. Thus it would easily lose a corpuscle, as before stated, but then the configuration would be as 58 (with, of course, an additional quantity of positive electricity), which is very stable, and tends to receive a corpuscle in the same way as 67, the element above it, added to which, of course, it has the now unbalanced positive charge on it, so that it attracts the corpuscle back again. Hence this element belongs to the zero, or inert group of elements.

Now, if element 60 loses a corpuscle, it does not tend to at once draw it back again, as it is then in a 59 position, which is still a losing corpuscle position.

Suppose, then, that elements similar to 60 and 67 come together.

Element 60 easily loses a corpuscle.

Element 67 easily gains one.

If, then, a corpuscle passes across from 60 to 67, one has left an excess of positive, the other an excess of negative electricity, and the two attract one another and stick together firmly. We thus have two atoms forming a molecule of a compound.

Generally speaking, the elements on the left represent electropositive elements (that is, they easily lose a particle of negative electricity), and on the right electronegative elements (that is, they easily obtain an extra unit of negative electricity). This is, of course, a very elementary system of atoms, and must only be taken as indicating the method of the combination of elements.

In the case of elements as they exist we are dealing with aggregations of not 50 or 60 units, but of 50 or 60 thousand corpuscles, and we would get a table reading something like 59,000, 60,000, 61,000, etc., so that an element may not only lose one corpuscle, but if very unstable (comparatively speaking, of course), as 60,000 it may lose not only one but as many as four corpuscles. One a little more stable, as 61,000, may only readily part with three corpuscles, and in this way we obtain the different valencies of the elements as we go across the table. Also, we may have a collection of corpuscles in an atom that will readily part with, say, either two or four of its members. This would give an element with two valencies—for instance, copper.

The mathematical difficulties concerning a collection of several thousand of these corpuscles arranged spherically have not yet, however, been overcome, so we cannot postulate definitely the properties of these collections.

Sir Oliver Lodge, in his book on "Electrons," says: "A proof that

the atom of matter is essentially composed of such electrons (that is, corpuscles) . . . is lacking. The electromagnetic theory of matter, unlike the electrotomic theory of light, must be regarded for the present as no better than a working hypothesis. It is a hypothesis of stimulating character and of great probability, but its truth is still an open question that is probably not going to be speedily closed."

To return to our molecule. When this molecule is split up into its constituents again, the corpuscle (or corpuscles, it may be) that went across return back, and leaves us the two atoms that we started with.

It is probably due to the passing back and consequent motion of this corpuscle that the extra powerful actions of nascent oxygen (as in bleaching) and nascent hydrogen, etc., are due. This motion across of the corpuscles also explains where the energy that is absorbed or given out in a chemical reaction goes to or comes from—it is electrical energy. Also, it is seen that chemical affinity is really electrical affinity, and hence the science of chemistry is only, after all, that of electricity in another guise.

There is one thing more concerning the atom. These corpuscles are all in motion in orbits around the centre of the atom, and the disturbance of the ether which they cause when revolving at a certain speed is known to us as light, and, of course, the atoms being set to each other at all angles, we get the light vibrations off in planes at all angles—that is, the light is not polarised.

The study of light, however, as influenced by the electric theory of matter, is a subject by itself, and I do not intend to enter into it here. It seems obvious (as a matter of fact it has been proved) that atoms of the same group, or vertical column in our tables, ought to have related spectra in virtue of their similar constitution. That the spectra of metals of the same group are related is an experimental fact.

We may imagine any of the groups shown in Fig. 1 to be rotating, and in most cases this will merely have the effect of increasing the distance of each unit from the centre. In certain cases, however, where there are two forms shown for the same number of magnets or corpuscles, it can be shown that the speed of revolution will decide which configuration will exist.

As regards the dimensions of the atom and its constituents. The linear dimension of an atom (the radius) is probably about one ten millionth of a millimetre, while a corpuscle only measures some one hundred thousandth of that. The mass of each corpuscle is somewhere between $\frac{1}{1000}$ and $\frac{1}{2000}$ of that of a hydrogen atom. Later results seem to show that the smaller value is more nearly correct. The mass of the atom is, as far as is known, made up of the sum of the masses of its constituent electrons.

Now I want to re-define the old idea of amperes and coulombs. When dealing with power we have been accustomed to consider amperes as the more fundamental unit, and coulombs as merely a product of amperes and seconds. Electromagnetic phenomena, too, have been considered in relation to the ampere.

That is, 1 ampere has a certain definite magnetic effect. (I purposely use the practical and not the absolute units for discussion here, so as the better to fix our ideas.) But a coulomb we know to be a certain definite quantity of electricity, just a certain number of corpuscles, whether at rest or in motion.

An ampere is just the rate of flow, that is, the passage of electricity at the rate of 1 coulomb or x corpuscles every second. That is, coulombs exactly correspond to gallons of water flowing in a pipe, coulombs being composed of x corpuscles in the same way that a gallon of water is composed of x molecules, and amperes directly correspond to flow in gallons per second.

It must then be established in the mind that the magnetic effects are not due merely to the passage of something indefinite, which we call "an ampere," but are due to the moving coulombs, and are, in fact, dependent on the momentum of the coulomb, that is to say, the momentum of all the corpuscles together, or the sum of the momentums of the individual corpuscles.

From this point of view it is easy to see why a moving sphere carry-

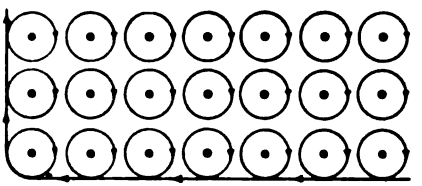


FIG. 2.

ing a charge should give rise to electromagnetic phenomena. Also a corpuscle in motion will give rise to electromagnetic effects.

Now we know of no such thing as absolute rest. The atoms themselves are in motion, and to the frequency of their vibration we give the name "temperature." The corpuscles in the atom, too, are in motion, probably in elliptical orbits (and the fact that they may be in orbits, which are not circles but ellipses, adds greatly to the mathematical difficulties of the subject). This means that the corpuscles will exert electromagnetic influences. In most substances there is no external effect, as the atoms are set at all angles to each other; but in a magnet these are polarised, so that they all act in the same direction (see Fig. 2). Here the circumferences of the circles may be taken to be the effective radius of the mean corpuscle, if one may coin a term, along which all the corpuscles of that atom may be taken to be revolving. Obviously, inside the body the "currents" neutralise each other, and there is merely the effect of a current going right round the outside of the metals, which causes the magnetic effects.

Also, if the material be divided, the two halves naturally both behave as magnets. This is, of course, practically the same as Ampere's theory of molecular currents—the old theory of magnetism in iron—only now

we have a better and more correct idea of these so-called molecular currents. Now it was shown, in 1881, by J. J. Thomson that a charged sphere in motion must have a certain inertia, due to the electromagnetic field it would create by its motion. And by having extra inertia, it will appear to have an increased mass. Now this increase of mass is very small and practically negligible unless the body has a very small mass compared with its electrical charge and a very high velocity. Now from the researches of Lenard, Kaufmann, Thomson, and others we are able to actually measure e, m, and v. And by applying Thomson's calculation to the values obtained for e and v, we can calculate out the apparent mass due to this electrical effect, and this result is within a few per cent. of the value obtained by measurement of m. This is true of particles, or corpuscles, with various velocities; as the velocity increases so does the apparent mass.

From this we draw the remarkable conclusion that the mass of the corpuscle is due to its charge and its velocity; to its electromagnetic effect on the ether, or as some authorities express it, this mass is due to

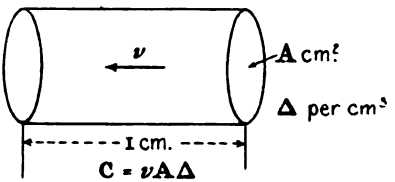


FIG. 3.

the "bound ether" which is carried along with the corpuscles. And since the mass of the atom is, as far as we know, entirely composed of the sum of the masses of its constituent corpuscles, then it follows that the whole of the mass of matter is electrical in origin, and is due to the drag on the ether by moving particles of electricity. Thus we see that the inertia of matter and the inertia of electricity, or self-induction, as we usually call it, are really one and the same thing.

I referred just now to a moving charged sphere as having a magnetic effect. If we imagine the magnetic effect of a conductor not to be due to 1 ampere, but to a flow of 1 coulomb per second, we get a better idea of the cause of this magnetisation. For if a flow of 1 coulomb per second causes a certain magnetic effect, then since that coulomb is composed of a number of corpuscles ($8{\cdot}7 \times 10^{18}$, to be exact), then a small proportion of that magnetic effect must be due to each of those corpuscles when in motion, so that any corpuscle in motion produces a magnetic field around it as it travels.

Consider unit length of a conductor of cross-sectional area (see Fig. 3).

We will assume the simplest case of an electric current—namely, where it is simply the steady uninterrupted flow of corpuscles from the negative to the positive.

Now unit length (1 cm.) of this conductor will have a certain magnetic effect, or magneto-motive force M.

Then let—

A = cross-sectional area of conductor in square centimetre.
v = the average velocity of the corpuscles.
m = the individual mass of each corpuscle—apparent mass, perhaps, I should say.
e = electrical charge (in coulombs) of each corpuscle.
Δ = the density or number of corpuscles per cubic centimetre (the number of free corpuscles per cubic centimetre is constant for the same (solid) substance).
c = current in corpuscles per second.
C = current in coulombs per second — that is, in *amperes*,

$$C = \frac{c}{K} \text{ where K equals } 8{\cdot}7 \times 10^{18}$$

hence—

$$c = \frac{1}{K}.$$

Then M, the M.M.F., is proportional to the sum of the electrical momentums of all the corpuscles in 1 cm. length.

M $\propto$ the whole charge of the corpuscles per unit length $\times$ their velocity.

$$M \propto (A \times 1 \times \Delta) \times e \times v$$

$$\propto \frac{A \Delta v}{K}.$$

Now v, the velocity, is such that c the current $= v \times$ corpuscles per unit length in corpuscles per second, that is—

$$c = v \times (A \times 1 \times \Delta),$$

and—

$$v = \frac{c}{A \Delta}.$$

Substituting in the above equation this value for v we get—

$$M \propto \frac{A \Delta}{K} + \frac{c}{A \Delta};$$

that is—

$$M \propto \frac{c}{K}$$

$$M = \text{a constant} \times C,$$

or the magnetomotive force per unit length of conductor varies merely as C the current in coulombs per second, or amperes as we usually term it. This, of course, we know to be true. So although the magnetic effect due to any one corpuscle varies as its speed, and is hence dependent on the area of the conductor and the density of corpuscles, yet the total magnetic force is always the same as long as a quantity of 1 coulomb passes any given plane per second.

The conduction of electricity in a solid is, however, not purely a steady passage of corpuscles as we have assumed above, but is really a series of exchanges. In an ordinary solid at rest (and here I am talking of conductors, not insulators) we think that corpuscles are constantly straying from their atoms, and after a short journey in the metal, finding a home in another atom, one of whose corpuscles has also gone off on a roaming expedition.

Still, however, as the sum total of all the corpuscles is constant, and so is the sum total of the positive electrification, the piece of metal remains uncharged.

Now if we apply an E.M.F. to the ends of the piece of metal, these atoms become polarised as it were, and all the corpuscles leave the atoms in the same direction and jump into the next one in the chain, so that there is a transference of electricity from the negative pole, and hence this would speedily become positively electrified were it not supplied with corpuscles from the source of supply of the E.M.F. The corpuscles have a very short, free path between the atoms and move along it with a very high velocity.

The subject of conduction by metals was treated fully by J. J. Thomson in his lecture before the Institution in February last.

In insulators the corpuscles do not readily free themselves from their atoms, they do not roam, and hence, even on the application of an E.M.F., they do not jump across from one atom to another, and so no current is conducted. Many insulators, as paraffin wax, glass, etc., do not readily enter into chemical combination, which also points to the same conclusion.

The resistance of a conductor has been defined as "the property whereby it absorbs the kinetic energy of the corpuscles and converts it into heat."

The conduction of current in liquids takes place in quite a different manner and is by means of dissociated atoms or ions.

Earlier in this paper I referred to chemical combination, in which one neutral atom lost a corpuscle and another neutral atom gained a corpuscle, the two combining chemically. Now suppose by some force these two atoms become separated without the transference of the corpuscle back again. We should then have one atom having a negative charge, and another having a positive charge, and these atoms would not behave as ordinary atoms on account of their charges, but until they had lost that charge they would not exist as the normal substance of which they were an atom.

Now such a force as the one I have described is water—just ordinary water. If a very weak solution of hydrochloric acid is made up the water dissociates nearly all the molecules of HCl and splits them up into H positively charged and Cl negatively charged, and these charged atoms are known as "ions." The hydrogen ion is positive, and is known as a "cation" (because it wanders to the cathode or negative plate, when a current flows). Similarly the chlorine ion is known as an anion.

If the solution is made stronger the number of molecules dissociated is greater, but not in proportion to its concentration, that is to say, the percentage dissociation is less with greater concentration.

Under the influence of an external electric force the cations drift slowly to the cathode and the anions to the anode, the total current being the sum of the two.

These ions move extremely slowly, so that for every ampere or coulomb per second which passes a given plane, since the velocity of the electricity is slow the number of corpuscles in the solution must be large.

It will be remembered that I have referred to the expression—

$$C = v A \Delta,$$

obviously since v is exceedingly small (being but a fraction of a centimetre per second) $A \times \Delta$ must be larger—as a matter of fact both A and Δ are larger, for with copper 1,000 amperes per square inch is quite common, while with an electrolyte only a few amperes per square inch is the normal density, and were one to apply such a voltage that would give a density of 1,000 amperes per square inch to an electrolyte (worked out from Ohm's law) the current would arc across through the electrolyte.

The extreme slowness of the corpuscles in an electrolyte is, of course, due to the fact that they are not free corpuscles, but are tied on to the large mass of an atom, forming an ion which they have to drag about with them. When an ion (either positive or negative) arrives at the electrode it yields up its corpuscle (if negative), or takes in one (if positive), and becomes the normal atom or collection of atoms; thus if a hydrogen ion is under consideration, it will become a hydrogen atom, and united mechanically with other hydrogen atoms formed in a similar manner, forms a bubble of hydrogen gas which escapes into the air. If it is an SO_4 ion (as in a solution of sulphuric acid) it will either attack the electrode when it is de-ionised, if of lead or other corrosive material, or else decompose a water molecule forming sulphuric acid and liberating an oxygen atom which will, when enough atoms have collected, be given off as a bubble of gas.

Though the magnetic effect of each corpuscle in a liquid is far less than that of one in a metal conductor, its velocity being much less, yet the total magnetic effect will, as has previously been explained, be exactly the same if the same number of coulombs per second be flowing. That this is actually so I have experimentally proved. My liquid conductor was a solution of common washing soda in a wooden trough 2 in. deep × 2 in. wide × 24 in. long; above this was placed an ordinary compass, and above this at a distance from it equal to the centre of the liquid conductor was placed a copper wire. The whole arrangement was placed in the magnetic meridian, so that when undeflected the needle pointed along the trough. The needle was deflected equally whether a current of a certain number of amperes was sent either through the liquid or through the copper wire—only, of course,

in opposite directions—as it was over one conductor and below the other. The object of having such a length of liquid conductor was to eliminate any effect due to the leading-in metallic conductors, which was, of course, negligible at the centre of the trough. Conduction in gases is also by means of ions, but is much freer than with liquids as the molecules of a gas not being packed anything like as closely as those of a liquid, progress of the ion is much easier. In a rarefied gas, as in a vacuum tube, some of the current may be in the shape of free corpuscles themselves.

Since the discoveries that have led to the formation of this theory have been largely connected with the various types of radiations that are given forth by matter, I have thought it advisable to give a brief account of the more important ones.

First, of course, there are the well-known ether waves, with a velocity of 3×10^{10} cm.-seconds. The longest are known usually as Hertzian waves, these having wave-lengths of from many miles to a few inches.

Lower down the scale come the heat waves, the longest of which have a wave-length of some $\frac{1}{1000}$ mm.; further on come the light waves with lengths of from about 700 to 400 micro-millimetres; and then the chemical rays shorter still, these last three series overlapping somewhat.

Though the subject of light is outside the range of this paper, any reference to radiations would be incomplete without mentioning these, to us, most important vibrations of the ether. The first kind of rays I shall mention are the cathode rays, first investigated by Crookes. These are shot out from the cathode of a vacuum tube when the gas therein is at a very low pressure, for a so-called vacuum tube never encloses a perfect vacuum, there is always a very small quantity of gas left in. To produce cathode rays the exhaustion must be carried on until the pressure is less than one ten thousandth part of an atmosphere.

These cathode rays in reality consist of corpuscles shot out with tremendous velocity (from 10,000 to 90,000 miles a second) from the cathode, and are, strictly speaking, not rays at all, as they have mass and electrical charge, and are in fact things and not mere wave motions to which alone the term rays should apply. These cathode rays cause a brilliant phosphorescence on the glass of the tube where they strike it, the colour depending on the composition of the glass. Glass which contains soda produces light of a greenish tint, while lead glass gives a bluish hue.

An opaque object will cause a shadow, as the corpuscles proceed in straight lines, the standard experiment being to have a mica cross in the tube, which casts a shadow. But if after some minutes working the cross be shaken down, the part which was previously in shadow now stands out more brightly than the rest, showing that the glass in time becomes fatigued to the action of these rays. The rays also have a mechanical effect, as they will set in motion a little paddle wheel which has been fitted inside a vacuum tube.

Corpuscles—or cathode rays—also affect some substances chemically, giving them a permanent coloration.

Cathode rays also have a heating effect. This is particularly noticeable if the cathode is made of concave section and the rays brought to a focus.

Lenard rays, so called after Lenard, who was the first to produce them, are merely cathode rays that have been brought into the atmosphere through a window of thin sheet aluminium fused into the vacuum tube. Lenard rays are stopped by all substances merely in proportion to their thickness and density. When cathode rays strike on the glass of the tube, or on a piece of metal within a tube, they produce Röntgen or X-rays. These are ether waves and are similar in constitution to light waves. There is one difference, however, and that is that each disturbance, caused by the impact of a corpuscle, very soon dies away, and hence the disturbance is only a few waves long (Fig. 4).

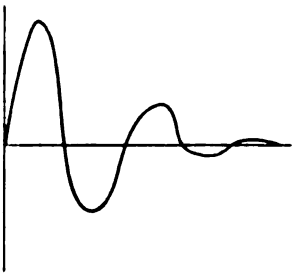


FIG. 4.

Light waves consist of a steady strain of thousands of waves, and it is due to this steadiness, and to the number of successive waves, that we obtain the phenomena of refraction, etc., and that we are able to measure the wave-length. So that the length of these Röntgen waves has not been measured, neither do we obtain any refractive or interference effects with them. These rays possess physiological effects. They also affect the photographic plate, and since bones are more opaque to these rays than flesh, we can obtain a shadowgraph or radiograph, as it is more usually called, of any part of the living human body.

X-rays also produce phosphorescence in certain substances, such as barium platino cyanide. Hence, if we coat a cardboard screen with this substance, and throw an X-ray shadow on to it the, to us, invisible picture at once appears on the screen, and so we can see a picture of the shadow of the bones of a living being.

Niewenglowski's rays are rays given off from such substances as calcium sulphide after it has previously been exposed to sunlight. These are simply electromagnetic ether waves or invisible light waves, if one may use such a term, which are more penetrating than those which we know as light, and hence will affect a photographic plate through a covering of black paper or aluminium. Becquerel rays were rays from substances which, unlike the above, needed no previous exposure to sunlight—that is to say, the emission was spontaneous. These rays were discovered from their effect on a photographic plate, and were first discerned in the case of uranium, and this experiment by Becquerel set in motion the researches of the Curies, which discovered to us the element radium and the radio-activity of certain elements of matter.

Radiographs, taken by means of the Becquerel rays, may be easily obtained by any one with practically no trouble at all, the active agent being mantles as used in incandescent gas lighting. The rays emitted are due to the thorium contained in the gas mantle, which, as will be mentioned later, is one of the radio-active elements. Since it is only the substance itself that we are concerned with, the mantles will do just as well for this purpose after they have been used for ordinary lighting purposes.

It is noticeable how opaque glass is to these rays. The elements which have the property of emitting these rays are known as radio-active. The radio-active elements are radium, thorium, actinium, uranium, polonium, radio-tellurium, and radio-lead, little being known as yet about the two latter.

These give out three types of rays, known as the α, β, and γ rays. The α rays are positively electrified, and have a large mass compared with their charge, the mass having atomic dimensions. The β rays are negatively electrified, and have very small mass. The γ rays are not charged at all, and hence are not deflected by a magnet. They have no mass, and are, in fact, ether vibrations.

Now let us refer back to our model atom. It will be remembered that for certain numbers of corpuscles there were two configurations which depended on the velocity of rotation.

Now if one of these slows down below the critical velocity it will change its configuration, and this change may be so violent as to blow away part of the atom, and an entirely fresh residual atom would be formed. This configuration might also be unstable, and after a certain time this in turn would split up, and this would go on till we again get a fairly stable configuration again.

Now this is just what happens with radium. Every second one atom in ten thousand million becomes unstable and splits up in this manner, and gives off α, β, and γ rays.

On examination we find that the α rays are positively electrified atoms of helium, the β rays are corpuscles, and the γ rays are identical with X rays, being due to the disturbance in the ether caused by the explosion of the atom.

The remainder, which is by far the larger portion of the original atom, forms the atom of a new element, and, in most cases after a certain time, also breaks up.

It is obvious that if on the average one atom in every so many breaks up, then when half the atoms of a given mass have broken up, the total emission is halved, and consequently the rate of decay of what is left of the original mass is also halved, so that the decay of a radio-active substance follows a hyperbolic law. From this it is impossible to give a definite time in which all the mass will have decayed, but the life of the mass is generally measured by the time in which it falls to half-activity, and this is rather a measure of the rate of decay than the actual time of total decomposition.

It is also found that a mass of pure radium does not really give out

α and β particles and γ rays, but that some of these effects are due to the subradiumic elements that are formed by the decay of the radium.

The following Table VII., graphically illustrated in Fig. 5, shows the successive products of radium :—

TABLE VII.

Substance.	Time Taken to Fall to Half-activity.	Rays Emitted.
Radium	2,000 years	α
Radium emanation ...	3·75 days	α
Radium A	3 minutes	α
Radium B	26 minutes	β
Radium C	19 minutes	$\alpha\ \beta\ \gamma$
Radium D (or radio-lead ?) ...	40 years	—
Radium E	6 days	β
Radium F (or polonium ?) ...	140 days	α

These substances, radium emanation A, B, C, etc., are all elements more or less unstable, but on account of the small amount that can be

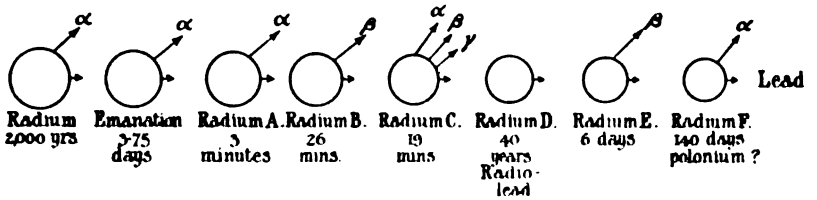


FIG. 5.

produced, and the transient life of most of them, their chemical properties have not been fully studied. Probably, however, they would fill empty spaces in the periodic law.

Radium emanation is an element that is gaseous at atmospheric temperature and pressure. It can be liquefied at about —150° C. by means of liquid air. The above elements being radio-active may be discerned by means of the electroscope. Radium emanation is the most powerfully radio-active element known, and fairly bombards its surroundings with millions of α particles.

There are other families of elements such as the thorium family (Fig. 6, Table VIII.).

TABLE VIII.

Substance.	Time of Half-decay.	Rays.
Thorium...	10^{10} years	α
Meso-thorium	(?)	β
Radio-thorium	2 years	α
Thorium X	3·7 days	α
Emanation	54 seconds	α
Thorium A	11 hours	
Thorium B	1 hour	α
Thorium C	(?)	$\alpha\ \beta\ \gamma$

There is a similar actinium family also uranium (Fig. 7, Table IX.).

TABLE IX.

Substance.	Time of Half-decay.	Rays.
Uranium	5×10^9 years	α
Uranium X	22 days	$\beta\ \gamma$
Ionium	—	$\alpha\ \beta$ (?)
Radium	2,000 years	—

Here I must quote Professor Rutherford, who, lecturing at the Manchester University last month, stated that it had been proved that radium was a disintegration product from uranium "quite conclusively." Also radium, as is well known, produces helium, the atoms of which are the α rays themselves; and probably lead is the final product of the residue.

This subject is, of course, still in its infancy; there will, doubtless, be many questions raised which not only am I unable to answer, but

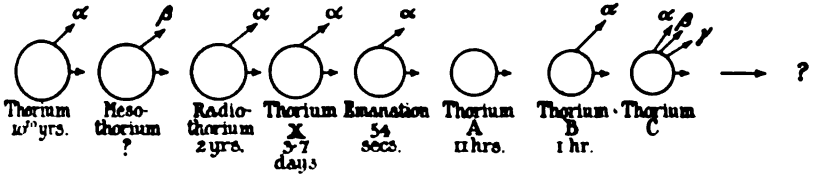


FIG. 6.

which no one can answer in the present state of our knowledge. Important research is still being carried out on these subjects. It is possible that with the aid of the strong bombarding action of radium emanation we may be able to cause elements naturally most stable to break up. Sir William Ramsay says he thinks he has evidence that when the emanation is mixed with water, small quantities of neon and argon are produced, and that when it is mixed with copper sulphate some nickel is formed. These results, however, are only tentative, and are stated with some reserve. It seems, then, that we are at the beginning of a new world of science, which tends to link together the older sciences of physics, chemistry, and electricity.

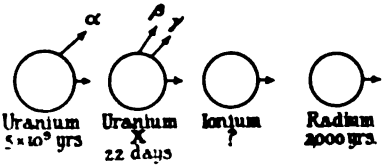


FIG. 7.

Though only a student of the subject, I have here endeavoured to show that the two terms with which I headed this paper—namely, "Electricity and Matter"—are synonymous.

THE "BROWN, McKENZIE" SYSTEM OF ELECTRIC BLOCK SIGNALLING ON RAILWAYS.

By ANDREW HAMILTON, Student.

(*Abstract of Paper read before the* STUDENTS' SECTION, *at* GLASGOW, *December*, 1907.)

The system dealt with in this paper is known as the "Brown, McKenzie" system. It is so designed that a train on entering a section automatically indicates its approach to the signalman controlling that section of the line, and also, if the line is clear, indicates its approach to the signalman in the cabin of the section ahead, and at the same time informs the signalman of the section immediately behind that it has entered the next section, thereby enabling him to open his section to a train following.

In this system of electric block signalling a conducting wire or rail *a* is laid along a section of the track at each signal cabin, forming the signalling area, as shown in Fig. 1. It is placed alongside the ordinary rail *b* and supported at intervals by suitable brackets properly insulated. A second conducting wire or rail *c* is laid parallel to the first conductor. In each signal cabin there is arranged a green, a red, and a white lamp, marked *g*, *r*, and *w* respectively in Fig. 1. Each lamp has in conjunction with it a call-bell suitably arranged in circuit. These lamps are referred to throughout as signal lamps.

An insulating wire *e* is led from the signal wire or rail *a* to the green lamp *g*, and is earthed by the wire *k*, and a branch wire *i* is led to a switch contact s' in the signal cabin A, and a second insulated wire *h* is led from the other signal wire or rail *c* by a branch wire i' to the switch contact s^2. By means of the switch *s*, when it is connected to the contacts s' s^2, a circuit is completed from the wires *i* and i', thereby connecting in the circuit the green lamp *g* and the danger lamp *r*.

Placed on the engine is a dynamo *o*, arranged with a distributing trolley *q*, which is normally pressed downwards by springs, so that on passing the signalling area the trolley *q* makes contact with the signalling rail *a*.

A collecting trolley *v* is also pressed downwards by springs and makes contact with the signalling rail *c*, and a collecting trolley *u* makes contact with the signalling rail *a*. The trolley *u* is connected by a wire u' to the wire *t*, and from the wire *t* by a branch wire t' to the green lamp g' in the cab of the engine, then to earth by the engine framing From the wire *t* there is also led a branch wire t^2 to the

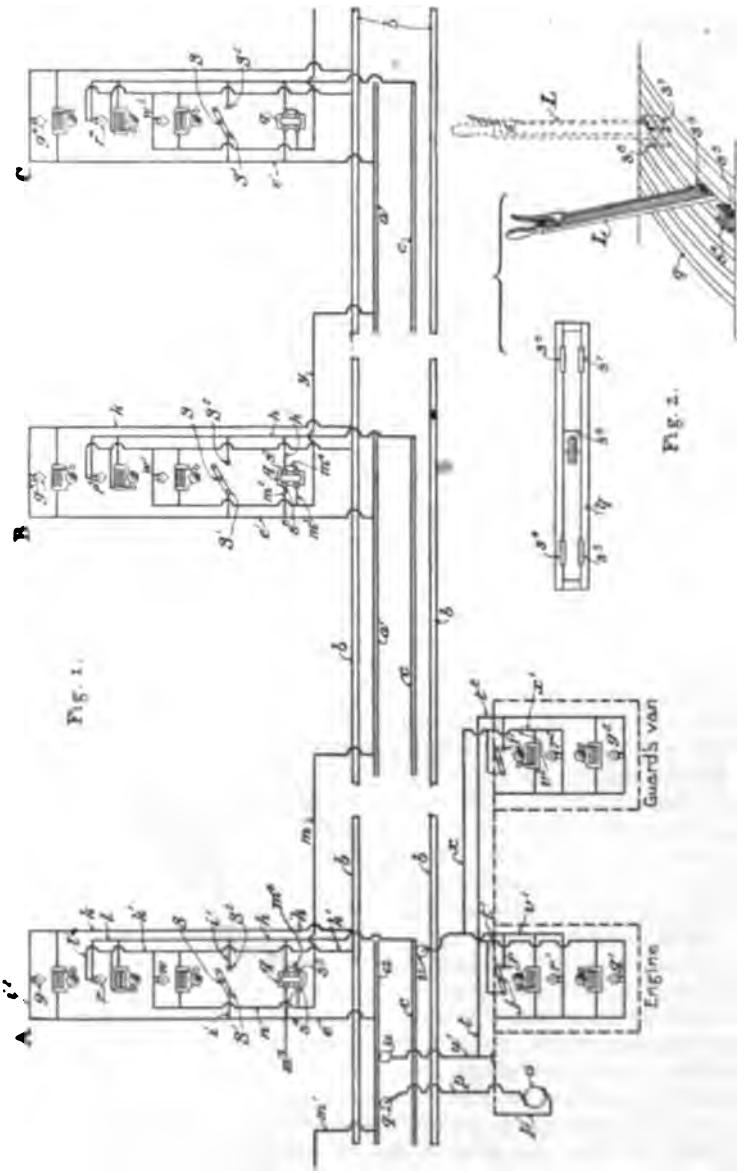


Fig. 1.

Fig. 2.

green lamp g^2 in the guard's van, and then it is earthed to the van framing.

The trolley v is connected by the wire v' to the red or danger lamp r' in the engine cab, and by a branch wire x to the red lamp r^2 in the guard's van. The two red or danger lamps r' and r^2, in the engine and guard's van respectively, are connected in circuit by the wire x and to the switch contact j', so that when the switch j, in either the engine or van, is brought into connection with the contact j', a circuit is completed between the signalling rails a and c, and the lamps r' and r^2 are lighted, and also the red or danger lamp in the signal cabin A, and, simultaneously, the green or call lamp g^3 is lighted in the signal cabin B ahead.

When the line ahead is clear and a train enters the signalling area A, the distributing trolley q forms a connection between the dynamo o and the signalling rail or wire a, and current from the dynamo o passes from thence by the wire e and the branch wire i^2 to the lamp g, and to earth by the wire k and rail b. At the same time the current passes by the collecting trolley u and the wires u', t, t', and l^2 to the lamp g' on the engine, and g^2 in the guard's van. In this manner a continuous light is maintained in the lamp g, in the lamp g', and in the lamp g^2, while the train is on the signalling area, thereby intimating to the signalman and to the engine-driver and guard that the train is in the signalling area, and, as the line ahead is clear, no further signal is required between the driver of the engine and the signalman ; but should the driver desire to call the attention of the signalman, he can do so by bringing his switch j into connection with contact j', a flash only, and thereby complete the circuit through the signalling rails a and c, thereby operating and lighting the red lamp r in cabin A and also the green lamp g^3 in cabin B. The reason for making the emergency signal a flash only is to indicate to the signalman in cabin B that the train is on section A, whereas if the train is on section B, a continuous light would appear in lamp g^3. This flash signal can be replied to by the signalman in signal cabin A by means of the switch s, which is brought into connection with the contact s^2, thereby completing the circuit between the contact rails a and c, and lighting up the lamps r^2 and r' in the guards van and engine cab respectively.

When the line ahead is *not clear*, the signalman throws the switch s into connection with the contact s^2, and keeps it there until the obstruction on the line is removed, so that when a train enters the signalling area under the control of that cabin, the circuit is completed between the signalling wires or rails a and c, and therefore, immediately the contact brushes or wheels q, u, v on the engine make contact with the signalling rails, a complete connection is formed between the dynamo o on the engine and the danger lamps r' on the engine, and r^2 in the guard's van, and also with the danger lamp r in the signal cabin A, thereby at once warning the engine-driver that the signals are against him, and intimating to the signalman that a train has entered his signalling area.

From the wire *e*, by means of the switch *s* and contact s^2, current is led by the branch wire *l* to the danger lamp *r*, and by the branch wire *l'* to the wire *k'*, and then to earth by the rail *b*. When the switch *s* is on the contact s^2 and signal at danger, provided an engine is on the area controlled by the signal cabin A, the lamps *r*, *r'*, and r^2 are all lighted as already explained, and also the green lamp g^3 in the signal cabin *b*, by means of the branch wire *m*, led from the wire *n* in the cabin of the signal area behind and from which wire *m*, a branch wire, is led to the white lamp *w* in the signal cabin of the area behind, so that this lamp will also be lighted when a train enters section A.

As shown in Fig. 2, the quadrant Q of the frame for the ordinary signal lever may be provided with contact studs s^4, s^5, s^6, s^7 arranged on either side of the slot. The lever L itself is provided with a contact piece s^8, so arranged that when the lever is thrown over to put the usual semaphore signal at danger a circuit is closed through studs s^6, s^7, and contact piece s^8.

Similarly when the lever L is pulled to the clear position on the quadrant Q another circuit is closed through studs s^4, s^5, and contact piece s^8.

A branch wire m^2 (see cabin B of Fig. 1) leads from the wire *e'* running to the green lamp g^3 in the cabin of the signalling area B, and is connected to the contact stud s^6 at the blocked end in the side of the lever quadrant Q. A branch wire m^3 connects wire *y* of the white lamp *w'* to stud s^4, and another branch wire m^4 connects stud s^5 with stud s^7; stud s^7 is connected, by a branch wire *h'*, with the danger wire *h* which is connected to the signalling rail *c*.

Supposing now a train to be entering the area B, it automatically lights the green lamp g^3 in signal cabin B, and simultaneously, by means of the wire *m* which is connected to the signalling rail *a'* and branch wire *n*, lights the white lamp *w* in the cabin A, and at the same time, if lever L in cabin A is at *clear* and the circuit closed through studs s^4, s^5, and contact piece s^8, will light the danger lamp *r* in this cabin A, indicating to the signalman that his section ought not yet to be opened to a succeeding train, as a train still occupies area B.

If the white lamp *w* in the cabin A is not lighted when the train, which has passed that area, arrives or should have arrived in area B, the signalman in area A knows that something is wrong, and by means of switch *s* he stops any train entering his section.

The signalling arrangements are such that a train cannot, without ignoring the signals, leave area A, whilst a train which has passed area A is not yet clear of area B, and so on for each signal area. When a train enters area A, and a train still occupies area B, and, say, by neglect the signal lever L in area A is left at *clear*, that is, pulled into contact with studs s^4, s^5, current will be conveyed from the train on area B, along the wire *m* to wire m^3, by studs s^4, s^5, wire m^4, branch wire *h'* to wire *h* and rail *c*, then by the trolley *v* of the engine entering area A, to the lamp *r'* on the engine and r^2 in the guard's van, thereby warning the driver and guard that a train still occupies the area B ahead.

When a train enters area A, after a train has left area B, but which has not yet reached area C, the signalman in area B is warned that a train has entered area A by the flash of his green lamp g^3, and, knowing that the train which has just left his area has not yet reached area C, he can be prepared to block the train from area A, if necessary.

Arrangements are also provided whereby the engine-driver is made aware of any fault in the working of the signalling gear. By means of apparatus an electric circuit to the engine cab is completed and lights a white lamp between the signal areas, and so long as this lamp remains lit the driver knows that the contact arrangement is working all right. When the train enters the next signalling area, an electrical connection is made with a green light g in the engine cab, and indicates to the engine-driver that he is in the signalling area. The green lamp will light if the road is clear, whilst if the road is blocked a red lamp will show in addition. When the train leaves the signalling area the white lamp is re-lit and keeps lit between the signalling areas.

A guard is fitted with a pocket to enable a suitable brush to be inserted for clearing off snow, etc., from the contact rails. A further guard is fitted to indicate to the driver when a heavy body or other obstruction between the rails interferes with the trolleys.

Means are provided whereby the train officials may be made aware of their approach to a level-crossing, an installation somewhat similar to that in a signalling area is used; but to distinguish between the two installations at the level-crossing the contact rails or wires are made with a series of depressions, so that the trolleys will have an intermittent contact with the wires, with the result that instead of a continuous light appearing in the signal lamps, a series of flashes are emitted from the lamps on the train.

With the contact rails and contact trolleys arranged to give the various clear and danger signals as I have described, the backing of a train on the line, or the running of the engine tender first, would upset the arrangement, and to overcome this difficulty a reversing apparatus is provided and arranged so that the act of pulling over the reversing lever of the engine reverses all the switches of the signalling apparatus, and thereby causes the proper lights to appear in the signal lamps, to indicate clear or danger as already described.

A very simple emergency means of communication between the driver and the signalman is provided which can be used between the signalling areas. This consists of a wire which, when it is desired to communicate with the signal cabin, is connected at one end to a switch on the engine cab, and the other end connected to the block signal wire running between the signal cabins. In this way a signal can be given in the signal cabin that something is wrong.

THE MOTOR CONVERTER.

By H. W. GREGORY, Student.

(*Abstract of Paper read before the* STUDENTS' SECTION, *in* LONDON, *March* 25, 1908.)

The principle of the cascade converter or motor converter may be studied by regarding the component parts separately.

Imagine a 6-pole 3-phase induction motor with a rotor furnished with three open-circuited slip rings, and the stator connected to a supply system having a frequency of, say, 50 ∿ per second. Also a synchronous motor with six separately excited field magnets, and 3-phase revolving armature rigidly coupled to the rotor of the induction motor. Imagine the rotating part driven externally by a belt till a constant speed representing half the synchronous speed of the induction motor, that is, 500 revs. per minute, is attained. The speed of the stator field being 1,000 revolutions the slip rings of the rotor and those of the synchronous motor will both be in a position to furnish 3-phase currents of 25 ∿, and if the voltages are equal and there is opposition of phase, the similar rings of each machine may be connected together without interchange of current.

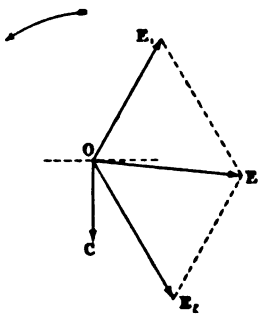


FIG. 1.

Let the speed of the prime mover be now slightly lowered. The result on the part of the synchronous motor as regards its field is to make its E.M.F. lag behind its former position, and on the part of the induction motor as regards the stator field to make its E.M.F. lead.

Fig. 1 shows the relative phase differences when there is a tendency to lower the speed of the rotating part. O E, is the vector E.M.F. for the synchronous motor; with respect to the synchronous motor, the induction motor E.M.F.'s are to have opposition of phase; O E, is this second vector E.M.F. The vector sum of O E, and O E, gives rise to an E.M.F. O E which will set up a controlling current with a lag due to the induction of the coils, say O C, which represents the actual current in the rotating part. The position of the conductors carrying this current when it is at a maximum may therefore be determined, due regard being given to the opposition in the sense of direction of the

vectors when considering each machine. These maxima currents occur in a strong field, tending to produce a forward motion in the case of both machines, thus opposing the tendency to reduce the speed. Hence the external driving power may be dispensed with, and on the addition of a commutator to the synchronous motor armature, making the latter a rotary converter, we obtain the simple motor converter.

On the loading up of the direct-current side it is evident that the state of balance of the rotor E.M.F.'s is upset, with the result that what might be termed a controlling current is set up between them, the component of which in the rotary converter armature being converted provides part of the direct-current load, and that in the rotor being in such a direction as to react on the stator field, producing a torque which drives the rotary converter armature as a direct-current generator, providing the remainder of the direct-current load.

The relative number of poles on the induction motor and rotary converter may be varied, but that the synchronous speed of the machine is dependent on the sum of the number of poles, and quite independent of the relative number of poles on each. With a given frequency and a given total number of poles, and therefore a given speed, with the greater number of poles, on the stator the speed of the stator field is low, the frequency of the induced currents will be low, and thus suited to the low frequency of the rotary converter with its fewer poles. The slip being low will tend to reduce rotor iron losses, but the machine will evidently be working more as an induction motor-generator than as a rotary with its transformers with resulting loss in efficiency, for the conversion of electrical into mechanical power must necessarily take place more inefficiently than if converted into electrical power as in the transformers of the rotary converter, which machine will therefore show a general gain in efficiency as compared with the motor converter.

The machine is also capable of being inverted, that is, run from the direct-current side supplying alternating-current power. It is also thus obvious that the machine may be built with any number of phases on the stator, and the single-phase motor converter in order to be capable of being started up as a single-phase induction motor is provided with a split phase winding inoperative when the machine is on load.

In most machines the stator is of the form usually supplied with induction motors and with the various designs of slots, but owing to the higher leakage coefficient with open slots there is a tendency to use the more costly semi-enclosed slot. For safeguarding the insulation from the voltage surgings on switching on extra high-tension machinery of this kind, a simple water-charging device has proved very effective.

The rotor of the induction motor is wound with the various designs of slots, and is wave-wound for 12 phases, the short-circuited slip rings providing the neutral point.

In the case of machines with two end bearings the 12 phases go straight across to the rotary converter armature, but when there is a centre bearing they are led through holes bored radially in a substantial coupling bolted direct on to the rotor spider, through the hollow shaft, out again on to the rotary.

The rotary converter armature is as a rule lap-wound, thus necessitating 12 tappings per pair of poles; the 12 phases are therefore connected to 12 concentric copper rings, from which consecutive tappings are taken, thus performing the duty of equaliser rings.

The voltage on the direct-current side being 100, that across phases on the rotary converter will be 18·3, assuming a sine distribution of flux, which is the voltage for which the 12 rotor phases must be designed.

The question of regulation involves variables: (1) Power factor, (2) direct-current voltage, (3) direct-current load. The variation in the first must be as small as possible, with big variations in the second and third. In order to raise the E.M.F. on loading the machine we increase the excitation. Now the armature impedance, which is dependent almost entirely on the reactance, when added to the applied E.M.F. gives the generated E.M.F. of the rotary converter to which the voltage on the direct side is due. As the excitation is increased so the lead increases, giving rise to further increase in the generated back E.M.F. Now, for a given increase in the leading of the current taken by the machine it is obvious that the E.M.F. on the direct-current side will increase more with a high value of the reactance than with a low one. In order to keep the power factor near unity with a large increase in direct-current voltage the reactance of the machine must be kept high. Moreover, the drawing of a leading current through the apparatus supplying the converter, whether it be transformers in the rotary or induction motor in the motor converter, has a similar effect of raising the induced E.M.F. above the applied E.M.F. to a greater or less degree dependent on greater or less reactance. Now the constructional features of the motor converter are such as naturally conduce to a high reactance greater than that in the rotary and its transformers, and the machine therefore permits of a great range in direct-current voltage without a similar range in power factor.

The excellent regulation thus offered by the motor converter renders it practicable to run the same machine on a lighting or traction load with a total range of voltage of at least 20 per cent. and a reasonable power factor in each case.

It follows from the foregoing remarks that the machine may be compounded for traction like the rotary converter and with better results as regards power-factor variation.

When a range of 30 per cent. or more is required on the direct-current side it is advisable to adopt the alternating-current booster method of controlling the voltage, which has been found so convenient in similar cases with the rotary converter.

The following is a comparison of the relative advantages of the rotary and motor converters:—

Efficiency.—The efficiency of the motor converter, especially in the smaller units, does not drop so rapidly with the load as the efficiency of the rotary converter. In the larger units the rotary converter shows an advantage of about 1½ per cent., and at ¼-load the efficiencies are about the same. This property of the motor converter would be useful in a lighting sub-station without a battery where a machine is always running on a light night or day load. It would appear that the no-load losses on the roatary are greater than on the motor converter, or the iron losses on the three transformers (considering always a 3-phase system) were greater than the stator iron losses and the smaller rotor iron losses which occur at half the frequency of the mains. As regards frequency the data for 25-~ machinery is less available than for 50 ~, however the efficiency of both machines will go up with the frequency, but the gain in efficiency of the rotary will be less marked at the high than the low frequency.

Prime Cost.—The costs of the two machines are substantially the same.

Starting.—The starting of rotary converters may be summarised as follows from the alternating-current side :—

1. By means of an auxiliary induction motor.
2. As an inverted induction motor by means of low-voltage tappings on the transformer.
3. From the direct-current side as a direct-current motor.

In sub-stations possessing a battery the third method is admittedly the best. The second method cannot be considered as otherwise than crude. The first is generally recognised as being the more satisfactory method of starting these machines where no battery exists. As regards the actual synchronising, the time taken by each machine is about the same, but the motor converter is undoubtedly the easiest machine to synchronise.

Switchgear.—The switchgear required by each machine when started from the direct-current side is the same, but when started from the alternating-current side the motor converter shows a great saving in the capital cost of these accessories. As regards the cost of cable, etc., for connecting up the machines to the switchboards, a great saving lies with the motor converter, and these cables contribute no small sum to the capital outlay of a sub-station.

Maintenance and Attention.—The maintenance on converting plant is remarkably small, but the considerable wear in the slip-ring brushes of rotary converters which carry heavy currents require special care to be bestowed on them. The motor converter has no parts requiring such attention.

Regulation.—For the reasons previously laid down the permissible voltage regulation on the direct-current side is greater in the motor converter than in the rotary converter. For special cases of wide regulation necessitating an alternating-current booster this accessory

is more adaptable and cheaper when applied to the motor converter than the rotary converter.

Fluctuation of Direct-current Voltage.—No fluctuation occurs in the direct-current voltage of rotary converters with a change of frequency but due to the direct-current generator element in the motor converter the direct-current voltage of this machine must vary to a slight extent with the frequency. On the other hand, the same direct-current element is responsible for a steadying effect with variations in the extra high-tension voltage, which effect is non-existent in the rotary.

Commutation.—The commutation of rotaries is, as a rule, excellent, as also is that of motor converters with commutating poles.

Reliability.—As regards freedom from breakdown it has been mentioned that for higher voltages on the stator of the motor converter a charging device is advisable.

For reliability under short circuits on the direct-current side the motor converter is undoubtedly superior.

Balancing a 3-wire Network.—A rotary converter supplying a 3-wire network will automatically balance the system by connecting the neutral wire to the neutral point of the low-tension star-winding of the transformer. In this respect the two machines are therefore on the same footing.

Reversibility.—Both machines permit of being run inverted from the direct-current side generating alternating-current power.

Floor Space.—The advantage here, if any, lies with the motor converter, owing to the transformers of the rotary.

Single-phase.—The rotating part of the single-phase motor converter is no different from that of the polyphase machine, and presents the enormous advantages as regards stability of twelve phases over a single phase.

Having duly considered the merits of these two types of machines, we are now in a position to enumerate the conditions of supply under which the various features of the motor converter render its use particularly suitable. These are as follows :—

1. For higher frequency circuits, that is, 50 ∿ and over.
2. For use where a great range of direct-current voltage is required.
3. For use when the adoption of an alternating-current booster becomes a necessity.
4. For single-phase systems.
5. And for use when running inverted.

In all these cases the advantages of the motor converter far outweigh the considerations as to its slightly lower efficiency.

STARTERS AND CONTROLLERS.

By P. C. JONES, Student.

(*Abstract of Paper read before the* STUDENTS' SECTION, *at* MANCHESTER, *January* 14, 1908.)

In a brief paper like the present, only the most superficial examination can be made of the various types of starters and controllers. In view of this fact only two distinct classes of controllers are dealt with, and these are "drum type" and "liquid type" respectively.

The chief points to be considered are—

1. What the apparatus has to perform.
2. How to perform it with the highest efficiency at reasonable cost.

Tramway controllers are subject to more trying and exacting conditions than obtained in almost any other application of electricity. They are in constant use and are handled by men who do not usually know when they mis-handle them. It is not a difficult matter to design a controller to make the required connections for cutting out the resistance step by step and reversing the motor, but the suppression of excessive arcing when opening circuit is not equally good in all types of controllers.

The Westinghouse Company have, amongst other types, a controller which is designed to split up the arc on opening circuit into a number of smaller arcs in series. On opening circuit, as the drum is returned to the "off" position, the length of the arcing path is easily increased beyond the distance over which the circuit could maintain an arc.

Another feature peculiar to a number of Westinghouse tramway controllers is that the same drums are used for reversing and braking, while usually with controllers of other makes the reverse and brake drums are separate.

A more recent design of tramway controller manufactured by the same firm is the T type, in which there are several entirely new features, amongst which it may be mentioned that the drums are all on one vertical shaft in the centre of the controller. The top is the reverse, the middle the main, and the bottom the brake drum. The fingers are on either side of the drums, and the arc shield which

separates the main drum fingers when in position, fits between two blow-out coils.

Leaving tramway controllers and passing on to those used for industrial work in connection with cranes, rolling mills, haulages, etc., it is found that for such classes of work the drum type controller is pre-eminent. For starting motors light and not many times each day, as is the requirement of most machine tools, pumps, fans, etc., the faceplate type of starter is quite satisfactory; but for rapidly starting and stopping motors against heavy overloads, which may occur several times in an hour, the drum type controller is more suitable. The drum type has its limitations, however, and for controlling motors of several hundred horse-power, electrically operated unit switches and liquid controllers take its place.

A type of industrial controller of Westinghouse design is constructed entirely of fireproof materials as required by the Admiralty, and it is largely used by them in the dockyard machine shops for cranes, etc. The drum is built up of iron castings clamped on to a steel shaft which is insulated with mica. On to the iron castings are secured the copper drum rings, which can be replaced when worn. The bases which support the fingers are likewise clamped on a mica insulated steel shaft.

In the controllers made by Dick, Kerr & Co., Ltd., the solenoid blow-out is used, and the reverse and brake drums are separate. The solenoid, which takes the place of the usual arc shield, does not cover up the drum to the same extent as the latter, and when in position only covers the fingers and that portion of the circumference of the drum at which the arc is broken.

The solenoid has an iron core on which is wound a number of coils so arranged with regard to their length and direction of turns that the magnetic field obtained when the coil is excited takes the form of several local fields passing as it were between the edges of the adjacent insulating partitions. As the partitions separate the fingers these latter will be cut by the lines. Between the insulating partitions spun copper shields are placed over the coils.

In the British Thomson-Houston Co.'s controller type R 27 the blow-out coil is at the bottom of the drum. The lines travel through the cast-iron main drum across the fingers into the iron back of the arc shield and complete the circuit through the frame of the controller.

One of the "Stellite" controllers, made by the Electric & Ordnance Accessories Company, Ltd., is designed to control a direct-current motor on the 3-wire system, the shunt field of which is always on the high voltage circuit. The motor starts with full field and the armature in series with resistance on the low voltage. The speed increases as the armature resistance is cut out, and is then further increased by inserting resistance in the shunt field circuit. For still higher speeds the armature is connected on the higher voltage and the field strengthened, and the speed is brought up to maximum by again cutting resistance into the field circuit.

Capstan controllers are generally operated by a foot pedal as they are mounted in the capstan case, the top of which is sunk level with the ground. As the labourer operating capstans in shunting yards and docks would not always remember to depress the pedal slowly in starting the motor, the controller is fitted with an overload circuit breaker to prevent damage to the motor.

On first depressing the pedal the circuit breaker is closed, and if it is further depressed so rapidly that the armature current rises above a pre-determined value an overload coil trips the breaker, and the pedal must be allowed to return, due to spring action, to its off position before the breaker can be re-set.

A controller of somewhat novel construction is made by the Phœnix Dynamo Manufacturing Company, Ltd. The moving portion which replaces the usual drum is of helical formation and has a thread of 1¼ turns, the pitch of which is equal to the distance between the centre of adjacent fingers. When the handle is rotated the helical piece is forced to slide along a square shaft by a rack in which it engages on the switch base. This starter has a no-load and overload release, and this latter has to be first closed by rotating the handle in a clockwise direction, and when the overload release or circuit breaker, which has a magnetic blow-out, is in position counter-clockwise rotation of the handle cuts out the resistance by the helical drum moving across the fingers which are connected to its various tappings.

Since there is a certain amount of wear on contact fingers and drum rings, due to sparking, it is necessary that these parts should be as cheaply renewable as possible. There should be no appreciable wear due to friction between the fingers and rings if these are kept lubricated with a slight application of vaseline. If no lubricant is used a quantity of copper dust will certainly be deposited inside the controller and may lead to serious burn-outs through short circuits. The best type of finger appears to be one in which a flat phosphor-bronze spring is used to press a copper tip of half-round section on to the drum. The spring should not form the main path for the current, but should be shunted by a flexible copper connection between the tip and terminal. The shunt and the tip are secured to the spring by a screw so that the tip can be easily and quickly replaced.

In many controllers the finger is bent from copper strip which is riveted to the spring and shunts. In replacing a finger of this type a new shunt and spring are also required, which will cost about 1s. as against 1d. for the renewable tip described above. Roller fingers are sometimes used, but these do not present any advantages over the kind using the small tips, except in the case of oil-immersed alternating-current controllers where the roller type is best. Generally speaking, a controller may be rated to carry 100 amperes per ¾ in. width of finger used.

The copper segments on the drum should be provided with small renewable tips as they are usually only burnt at the point where contact is broken.

The controllers described so far have been for direct-current circuits, and for the rheostatic control of multi-phase motors so largely used a somewhat similar controller is employed. The function of the multi-phase rheostatic controller is to make and break the line connections to the stator windings and to cut resistance in or out of the rotor circuit. The majority of motor manufacturers make the rotor windings in the 3-phase form, independent of whether the starter is for 2- or 3-phase supply, and whether the rotor windings are delta or star connected, the controller is most commonly arranged for use with star-connected resistance.

The arc shield is not essential as in direct-current work owing to the fact that a low voltage alternating-current arc is short and fierce, but does not tend to spread and flame like a direct-current arc. The cost of an alternating-current magnetic blow-out would be prohibitive in most cases as all the iron circuits used would have to be laminated and several separate exciting coils would have to be used.

On voltages above 600, which are fairly common up to 3,000, it is usual to immerse the controller drum and fingers in oil.

Liquid controllers can be used for both polyphase and direct-current motors. They differ from the drum type by using a resistance which is liquid instead of metallic, and the liquid is contained in the tanks which form part of the controller. A great advantage possessed by the liquid type is that a very even starting torque can be exerted by the motor under its control, owing to the fact that the resistance is cut out continuously and gradually, and not in a succession of steps as in the drum type. The resistance solution is very cheap, as it merely consists of common washing soda in water. Liquid controllers, which are used for speed regulation, are generally fitted with cooling coils placed in the electrolyte through which cooling water is circulated.

Proceedings of the Thirty-sixth Annual General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution, 92, Victoria Street, Westminster, S.W., on Thursday, May 28, 1908—Colonel R. E. CROMPTON, C.B., President, in the chair.

The minutes of the Ordinary General Meeting, held on May 21, 1908, were taken as read, and confirmed.

Messrs. T. Cushing and F. W. Hewitt were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Associate Members.

George Basil Barham.
William Thomas Bower.
William Buchanan.
Harry Burge.
Ernest Coleridge Churchwood.
Edgar Harry Cockshott.
John Gillan Doran.
John I. Gear.
John William Hogg.
George Eric Mason.
Joseph Andrew O'Brien.
William Bowman Packham.
Frank Ernest Saunders.
Walter Pembroke Scott.
William Arthur Scott.
Francis George Sherwood.
Herbert Eden Sutton.
Albert Stewart Tresilian.
Edward Beesley Trimmer.
William Espeut Vidal.

As Associate.

Thomas Taylor.

As Students.

Stanley Charles Bennett.
William Harold Haselgrove.
Bertram James Watson.

REPORT OF THE COUNCIL FOR PRESENTATION TO THE ANNUAL GENERAL MEETING OF MAY 28, 1908.

At this, the thirty-seventh Annual General Meeting of the Institution of Electrical Engineers, the Council present to the Members their Report for the Session 1907–8.

Death of Lord Kelvin.

In December last the members of the Institution received with profound sorrow the announcement of the death of Lord Kelvin, President and Honorary Member of the Institution. It will be within the memory of all that as President-Elect in the summer of 1907 he attended the Annual Conversazione, and, accompanied by Lady Kelvin, he assisted in receiving the Members and guests of the Institution, this being the last occasion upon which he took part officially at a general gathering of the Members. To the great disappointment of the Members he was prevented by Lady Kelvin's illness from occupying the Chair as President at the opening of the new Session on November 10th. For the same reason it became necessary to abandon the Annual Dinner, which had been arranged to take place about the same time.

On receiving the news of his death all ordinary business was suspended at the General Meeting, held two days later. The meeting was adjourned after a brief reference by the Chairman, Mr. Charles P. Sparks, to the great loss sustained by the Institution, and after passing a resolution of condolence with Lady Kelvin. Telegrams of condolence were also received from the Local Sections of the Institution at home and abroad, and from the Associazione Elettrotecnica Italiana and the American Institute of Electrical Engineers, of both of which Societies he was an Honorary Member.

The Institution joined with the Royal Society in requesting for Lord Kelvin the honour of burial in Westminster Abbey, and on permission being granted, the Royal Society undertook the necessary arrangements for the funeral. Dr. R. T. Glazebrook, F.R.S., Past-President, acted as one of the pall-bearers, and Colonel R. E. Crompton, C.B., Past-President, Officer Commanding the Electrical Engineers (London Division), of which Lord Kelvin was Honorary Colonel, attended with the officers of that Division to form a guard of honour. The Institution was further represented by Sir William H. Preece, K.C.B., F.R.S., Mr. C. E. Spagnoletti, Mr. Alexander Siemens, Sir Henry C. Mance, C.I.E., Mr. R. Kaye Gray, and Sir John Gavey, C.B., Past Presidents, by Mr. C. P. Sparks, Mr. F. Gill, Dr. G. Kapp, Vice-Presidents, and by Mr. W. Duddell, F.R.S., Mr. R. Hammond, Dr. E. Hopkinson, Mr. W. Judd, Mr. J. E. Kingsbury, Mr. W. M.

Mordey, Mr. W. H. Patchell, and Mr. A. A. C. Swinton, Members of Council. Dr. Silvanus P. Thompson, F.R.S., Past-President, attended as the representative of the Italian Electrotechnical Association.

In the absence of Lord Kelvin as President at the beginning of the Session, and until his death, the business of the Institution was most ably conducted by the Senior Vice-Presidents, Mr. Charles P. Sparks and Mr. Frank Gill, who shared the duty of presiding at Council and Ordinary General Meetings.

With the number of the *Journal* issued in April a portrait of Lord Kelvin was published, together with a brief memoir of his career.

At the first meeting of the Council in the new year consideration was given to the election of a new President, and Colonel R. E. Crompton, C.B., Past-President, was unanimously chosen to fill the office of President for the remainder of the Session.

Kelvin Lectureship.

As a memorial of Lord Kelvin's work and connection with the Institution, the Council resolved to found a Kelvin Lectureship, with the object of holding annually a Kelvin Lecture at a General Meeting. The first of these lectures was delivered on April 30th before a crowded audience by Dr. Silvanus P. Thompson, F.R.S., Past-President, who chose as his subject "The Life and Work of Lord Kelvin." The lecture is now printed in this volume of the *Journal*, page 401.

Growth of the Institution.

Since the date of the last Annual General Meeting, 201 proposals for election to corporate membership, and 312 proposals for election as Student have been considered, and there have been elected 7 Members, 165 Associate Members, 17 Associates, and 303 Students. The names of 1 Member and 1 Associate have been restored to the register, the total addition to the Roll of the Institution being 494, against which there has to be set the decrease owing to deaths, resignations, and erasures from the List of Members.

To the class of Members there have been transferred 45 Associate Members and 5 Associates, to the class of Associate Members there have been transferred 43 Associates and 96 Students, and to the class of Associates there has been transferred 1 Student.

The Council have had occasion during the past year to congratulate several members of the Institution upon whom honours have been conferred.

In 1907, on his retirement from the position of Engineer-in-Chief to the General Post Office, Sir John Gavey, C.B., Past-President, was created a Knight. Sir J. Irving Courtenay, Member, also received the honour of Knighthood. The Right Honourable Sir W. B. Gurdon, C.B., K.C.M.G., Associate, was appointed a Member of the Privy Council. Lieutenant-Colonel A. H. Bagnold, R.E., C.B., Member, and Professor

James A. Ewing, C.B., Member, received the Order of Commander of the Bath, and Mr. E. H. Lamb, C.M.G., Associate, was created a Companion of the Order of St. Michael and St. George.

The change in the Roll during the past twelve months is shown in the following table :—

	1907.	1908.
Honorary Members	7	5
Members	1,055	1,093
Associate Members	1,982	2,182
Associates	1,268	1,136
Students	1,517	1,543
Foreign Members	116	109
Total	5,945	6,068

Members Deceased.

Reference has already been made to the death of Lord Kelvin.

With deep regret the Council has also to report the death of Mr. Francis Hughes Webb (formerly Secretary of the Institution), which took place at his residence in Hampstead on May 17, 1908. Mr. Webb held the office of Secretary for twenty years, and by his unfailing courtesy and kindliness had endeared himself to all members with whom he came in contact. After his retirement in 1898 he remained an Associate and continued to take a close personal interest in the progress and welfare of the Institution with which he was so long and honourably connected.

The names of other well-known Members who have died during the last twelve months are Mr. James N. Shoolbred, B.A., Mr. W. E. L. Gaine, General Manager of the National Telephone Company, and Mr. E. Danielson, of Westerås, Sweden, Foreign Member.

A short account of the careers of members deceased will be found in the obituary notices published in the *Journal*.

The list of those who have died during the past Session is as follows :—

President and Honorary Member.

The Right Hon. Lord Kelvin, O.M., G.C.V.O.

Members.

R. V. Boyle, C.I.E. | W. E. L. Gaine.
J. N. Shoolbred.

Associate Members.

G. H. S. Drewett.	George Stevenson.
J. Edgar.	H. Topham.
J. E. Mellor.	J. Woodside.

Associates.

P. Dewhirst.	W. T. Tunbridge.
H. H. Hodd.	F. H. Webb (*Sec.*, 1878–98).
C. A. Morgan.	J. J. Wright.

Foreign Members.

E. Danielson	C. Poulsen.
Rev. E. Lafont, S.J., C.I.E.	O. Straube.

Students.

G. O. Earle.	S. C. Kefford.
R. H. Gardner.	H. V. Lewis.

Resignations.

4 Members, 16 Associate Members, 37 Associates, 2 Foreign Members, and 118 Students have resigned since the date of the last Annual Report.

Meetings and Papers.

During the past Session 19 General Meetings and 21 Council Meetings have been held. The usual standing Committees have met regularly throughout the Session, and several Occasional Committees appointed by the Council for the consideration of special matters coming before them have also met, the total number of Committee Meetings held during the Session being 100.

There have been 48 meetings of Local Sections, namely, at Birmingham 7, at Dublin 6, at Glasgow 6, at Leeds 7, at Manchester 9, at Newcastle 7, and at Capetown 6.

Annual Dinners and other social functions were held at Dublin, Glasgow, Leeds, Manchester, and Newcastle, which were well attended by members and guests. Members of Council also availed themselves of the opportunities thus afforded of meeting the members resident in the Provinces.

At the beginning of the Session under review, the Council, in consultation with the Committees of the Local Sections, introduced a new method of dealing with papers offered to the Institution for reading and publication. Since the inauguration of the Local Sections up to last year, each centre had undertaken the responsibility of selecting papers for reading and discussion, with the result that valuable and important papers were sometimes read at one centre only, with scarcely sufficient regard to their interest to the Institution as a whole. Under the new arrangement all papers, whether

offered direct to the head office or to the Local Section Committees, are submitted before reading or publication to the Papers and Editing Committee in London, specially appointed for the purpose, upon which each Local Section is represented by its Chairman for the time being, or, in case of his inability to attend, by the Local Hon. Secretary. The Chairmen have devoted much of their valuable time to attending the meetings of this Committee. The function of the Committee is to make recommendations to the Council as to the acceptance of papers for publication, and as to whether they can be usefully read and discussed at the General Meetings in London and at one or more Local Sections, due regard being paid, in the case of papers from Local Sections, to the wishes of the Local Section of origin.

Copies of all papers approved by the Council for publication are circulated as soon as possible to the Hon. Secretaries of all the Local Sections. From these it is open to all Local Section Committees to select any paper which they may consider of interest to the members in their district for inclusion in their programmes. One reservation only is made—namely, that in the case of papers put down for reading in London, these cannot be read and discussed elsewhere earlier than the week in which they come before the General Meeting in London. Thus the new scheme makes it possible to read any paper practically simultaneously at several centres if desired, and advantage has been taken of this arrangement in several instances in the past Session.

Besides many papers of importance submitted in the usual way for reading and discussion, two events in the programme of special interest to Members were the lecture by Sir William H. Preece, K.C.B., Past President, on his recent visit to America, and the First Kelvin Lecture, delivered by Dr. Silvanus P. Thompson, Past President, already referred to.

The following is the list of papers and lectures, with the places where read or delivered :—

List of Papers.

"The Dielectric Strength of Insulating Materials and the Grading of Cables," by Dr. A. Russell, Member. (Read in London.)

"The Development of Turbo-generators," by Dr. R. Pohl, Associate Member. (Read in London and Leeds.)

"Automatic Cab-signalling on Locomotives," by J. Pigg, Member. (Read in London and Newcastle.)

"Cost of Electrical Power for Industrial Purposes," by J. F. C. Snell, Member. (Read in London, Dublin, Glasgow, and Leeds.)

"Standard Performances of Electrical Machines," by R. Goldschmidt, Associate Member. (Read in London.)

"Protective Devices for High-tension Transmission Circuits," by J. S. Peck, Member. (Read in London, Manchester, and Dublin.)

"Electrical Power in Railway Goods Warehouses," by H. Henderson, Associate Member. (Read in London and Newcastle.)

"Electric Power in Docks," by C. E. Taylor, Associate Member. (Read in London and Newcastle.)

"Fuse Phenomena," by A. SCHWARTZ, Member, and W. H. N. JAMES, Associate Member. (Read in London and Manchester.)

"America Revisited, 1907," Lecture by SIR W. H. PREECE, K.C.B., F.R.S., Past President. (Delivered in London.)

"New Alternate Current Instruments," by Dr. W. E. SUMPNER, Member, and J. W. RECORD, Associate Member. (Read in London and Birmingham.)

"High Speed Electrical Machinery," by G. STONEY, Member, and A. H. LAW, Associate. (Read in London and Newcastle.)

"Electric Supply Prospects and Charges as affected by Metallic Filament Lamps and Electric Heating," by H. W. HANDCOCK and A. H. DYKES, Members. (Read in London, Dublin, and Glasgow.)

"The Life and Work of Lord Kelvin" (First Kelvin Lecture), by Dr. SILVANUS P. THOMPSON, F.R.S., Past President. (Delivered in London.)

"The Manufacture of Electrical Condensers," by G. F. MANSBRIDGE, Member. (Read in London.)

"Switchgear Control Apparatus and Relays for Alternating-Current Circuits," by Dr. C. C. GARRARD, Member. (Read in London.)

"Recent Progress in Tungsten Filament Lamps," by H. HIRST, Member. (Read in London.)

Inaugural Address by Dr. G. KAPP, Chairman, Birmingham Local Section. (Delivered in Birmingham.)

"Torque Conditions in Alternate-current Motors," by V. A. FYNN, Member. (Read in Birmingham.)

"Heat Conductivity of Iron Stampings," by T. M. BARLOW, Student. (Read in Birmingham.)

"Artificial Load for Testing Electrical Generators," by R. K. MORCOM and Dr. D. K. MORRIS, Members. (Read in Birmingham.)

Inaugural Address by T. TOMLINSON, Chairman, Dublin Local Section. (Delivered in Dublin.)

Inaugural Address by Professor F. G. BAILY, Chairman, Glasgow Local Section. (Delivered in Glasgow.)

"Polyphase Induction Motors—Choice of Type," by G. STEVENSON, Associate Member. (Read in Glasgow.)

Inaugural Address by Professor G. D. ASPINALL PARR, Chairman, Leeds Local Section. (Delivered in Leeds.)

"The Magnetic Testing of Iron," by W. H. F. MURDOCH, Associate Member. (Read in Leeds).

"The Commercial Aspect of Electric Power Supply," by W. B. WOODHOUSE, Associate Member. (Read in Leeds.)

"Wiring Rules of the German Society of Electrical Engineers," by W. P STEINTHAL, Associate Member. (Read in Leeds.)

"Heating of Ventilated and Enclosed Motors," by W. HARTNELL, Member. (Read in Leeds.)

"Electrical Driving of Textile Factories," by H. W. WILSON, Associate Member (Read in Manchester.)

"Magnetic Oscillations in Alternators," by G. W. WORRALL, Associate Member. (Read in Manchester.)

"The Reluctance of the Air-gap in Dynamos," by T. F. WALL, Student. (Read in Manchester and Birmingham.)

"Direct-current Turbo-generators," by W. HOULT, Associate Member. (Read in Manchester.)

"Electrolytic Corrosion," by Dr. W. W. HALDANE GEE, Associate Member. (Read in Manchester.)

"Management of Engineering Works," by E. THOMAS. (Read in Manchester.)

Inaugural Address by J. PIGG, Chairman, Newcastle Local Section. (Delivered in Newcastle.)

"Experimental Determination of the Losses in Pole Shoes due to Armature Teeth," by T. F. WALL, Student, and S. P. SMITH. (Read in Newcastle and Birmingham.)

"The Design and Use of Telephone and Telegraph Cables," by F. TREMAIN, Member. (Read in Newcastle.)

In addition to the above-mentioned papers the following have been accepted as "Original Communications," and printed in the *Journal*:—

"A Method of Plotting the Hysteresis Loop for Iron, with an Application to a Transformer," by Dr. G. KAPP, Vice-President.

"The Air-gap Correction Coefficient," by P. H. POWELL, Associate Member.

"The Potential of Partially Insulated Systems in Relation to the Potential of Earth," by M. B. FIELD, Member.

SALOMONS SCHOLARSHIP.

The Council have awarded two Salomons Scholarships, value £50 each, to—Mr. HERBERT CARNEGIE, of the Finsbury Technical College, London; and Mr. ALFRED HUTT, of the Central Technical College London.

DAVID HUGHES SCHOLARSHIPS.

A David Hughes Scholarship, value £50, has also been awarded by the Council to—Mr. CLIFFORD HIGGINS, of the Central Technical College, London.

ANNUAL PREMIUMS.

The following premiums for papers and communications have been awarded by the Council this year. In accordance with precedent, in deciding upon these awards the Council have not taken into account papers contributed by members at present holding office on the Council.

The INSTITUTION PREMIUM, value £25,

to Mr. G. STONEY (Member) and Mr. A. H. LAW (Associate), for their paper on "High Speed Electrical Machinery."

The PARIS ELECTRICAL EXHIBITION PREMIUM, value £10,

to Mr. J. S. PECK (Member), for his paper "Protective Devices for High-tension Transmission Circuits."

An EXTRA PREMIUM, value £10,

to Mr. J. F. C. SNELL (Member), for his paper on "The Cost of Electrical Power for Industrial Purposes."

An EXTRA PREMIUM, value £10,

to Dr. A. RUSSELL (Member), for his paper on "Dielectric Strength of Insulating Materials and Grading of Cables."

An EXTRA PREMIUM, value £10,

to Dr. W. W. HALDANE GEE (Associate Member), for his paper on "Electrolytic Corrosion."

An EXTRA PREMIUM, value £10,

to Mr. T. M. BARLOW (Student), for his paper on "Heat Conductivity of Iron Stampings."

STUDENTS' PREMIUMS.

A First Students' Premium, value £10, to Mr. H. R. SPEYER (Frankfort-on-Maine), for his paper on "The Electrification of the Mansfeld Copper Mines."

A Second Students' Premium, value £8, to Mr. L. H. A. CARR (Manchester), for his paper on "Electricity and Matter."

Three Students' Premiums, each of the value of £5, to Mr. A. HAMILTON (Glasgow), for his paper on "The Brown, McKenzie System of Electric Block Signalling"; to Mr. H. W. GREGORY (London), for his paper on "The Motor Converter"; and to Mr. P. C. JONES (Manchester), for his paper on "Starters and Control Gear."

Those Students' papers which gained a premium have been printed in the *Journal* in full or in long abstract.

STUDENTS' SECTION.

At the opening meeting of their session an address to the students was delivered by Mr. Robert Hammond on the subject of "Electrical Legislation."

Nine meetings altogether of the Students' Section have been held in the Library of the Institution, at which seven papers have been read and discussed. The Students' Committee also organised a visit to Switzerland in the summer of 1907, where they visited the following works, laboratories, and other places of interest: Messrs. Brown-Boveri & Co., Ltd., Messrs. Escher Wyss & Co., Maschinenfabrik Oerlikon, Messrs. Sulzer Bros., Schweizerische Lokomotiv und Maschinenfabrik, at Winterthur, the Zürich Polytechnic and the Jungfrau Electric Railway Company.

The arrangements of the visit were planned and carried out by the Chairman, Mr. E. W. Moss, and his Committee, and the great success of the visit was largely owing to Mr. Moss's skilful organisation of the expedition. The party was everywhere most kindly and hospitably received.

A series of visits to works and laboratories in and about London was made during the session, and the Annual Dinner of the Students' Section, held on March 24th, was very well attended.

The Manchester Branch of the Students' Section has also completed a successful session, having held seven meetings and read seven papers. Visits to various works in the district were also organised by kind permission of the firms concerned. The Students' Committee at Manchester are to be congratulated on the success of the Section in that centre.

Two meetings have also been held by the Glasgow Branch of the Students' Section, at which two papers have been read under the chairmanship of Professor Magnus Maclean.

The list of those papers by students for which premiums have been awarded is given above.

Incorporation of the Imperial College of Science and Technology.

In July, 1907, the Imperial College of Science and Technology was incorporated by Royal Charter, Article IV. of which provides that among other Personages and Authorities the leading scientific societies shall nominate each one representative to be a member of the governing body, the term of office for each member being four years. The Council accordingly appointed Mr. Robert Kaye Gray, Past President, as the first representative of the Institution upon the governing body of the College.

Home Office Regulations for the Use of Electricity in Factories.

By the courtesy of the Home Office the Institution was invited last year to consider and offer observations upon the new Draft Regulations prepared by the Secretary of State in pursuance of the Factory and Workshop Act (1901). The question was referred to the Traction, Light, and Power and the Parliamentary and Industrial Committees in joint meeting, with Mr. Alexander Siemens, Past President, as Chairman. The Committee devoted many sittings to the work, and the Council in due course received their report containing suggestions for the amendment of the Rules, which were submitted to the Home Office. Subsequently Mr. James Swinburne, F.R.S., Past President, was appointed Commissioner by the Home Office, to conduct a public inquiry, at which Mr. Alexander Siemens again gave his services by attending on behalf of the Institution.

Wiring Rules.

The issue of the revised edition of the Wiring Rules was reported at the last Annual General Meeting. Owing to the large demand for copies it was found necessary to reprint them in June, and in all about 3,600 copies of the new edition have been distributed. It is satisfactory to note that the Rules have been adopted by 36 fire offices and that 30 local authorities and supply companies have agreed to accept them as standard practice and to recommend their use.

The Committee hopes to resume its meetings in the autumn to consider such proposed amendments as have already been received, and also to revise the Rules as far as may be rendered necessary by the putting into operation of the new Home Office Regulations.

British Electrotechnical Committee.

The British Electrotechnical Committee was appointed by the Council on July 26, 1906, to act under and in accordance with the proposed Rules of the International Commission, which were provisionally agreed to at the Preliminary Meeting, held in June, 1906, in London. Sir John Gavey, C.B., was appointed President and Sir William Preece, K.C.B., and Mr. Alexander Siemens Vice-Presidents of the Committee. The full list of the Committee is as follows :—

Sir John Gavey, C.B. (*President*).

Sir Wm. H. Preece, K.C.B., F.R.S.
Mr. Alexander Siemens
} (*Vice-Presidents*).

The Rt. Hon. Lord Rayleigh, O.M., F.R.S.	Mr. T. Mather, F.R.S.
Colonel R. E. Crompton, C.B.	Mr. H. W. Miller.
Colonel H. C. L. Holden, F.R.S.	Mr. W. M. Mordey.
Mr. W. Duddell, F.R.S.	Professor J. Perry, F.R.S.
Mr. Kenelm Edgcumbe.	Mr. Charles P. Sparks.
Dr. R. T. Glazebrook, F.R.S.	Mr. James Swinburne, F.R.S.
Mr. R. Kaye Gray.	Professor S. P. Thompson, F.R.S.
Mr. Robert Hammond.	Mr. A. P. Trotter.
Dr. Gisbert Kapp.	Mr. E. B. Vignoles.
	Mr. C. H. Wordingham.

Mr. G. C. Lloyd (*Honorary Secretary*).

Mr. C. le Maistre (*Secretary*).

In accordance with the Rules of the Institution the Committee is re-appointed annually. It has full direction of the work of the Sub-Committees, of which at present two have been appointed, the Sub-Committee on Nomenclature, with Mr. A. P. Trotter, the Electrical Adviser to the Board of Trade, as the Chairman, and the Sub-Committee on Symbols, appointed January 16, 1908, with the Right Hon. Lord Rayleigh as the Chairman and Professor Silvanus P. Thompson the Vice-Chairman.

At the second meeting of the Committee, Colonel Crompton, the Honorary Secretary of the Commission, reported that committees had been formed in Austria, Belgium, Denmark, France, Germany, Hungary, Mexico, Spain, Sweden, and the United States, and that the matter was being considered in Australia, the Argentine Republic, Canada, Japan, South Africa, and Switzerland. With regard to Italy, he understood from Mr. G. Semenza, who had been a delegate at the Preliminary Conference, that there was every likelihood of a committee being formed there at no very distant date.

Owing to the death of Lord Kelvin the office of President of the Commission became vacant, and steps to fill the vacancy will be taken at the next meeting of the Commission.

According to the Rule which provides that each committee shall elect one delegate to the Council of the Commission, Dr. R. T. Glazebrook, F.R.S., has been appointed British Delegate, and, together with Sir John Gavey, C.B., President of the Committee, will attend the meeting of that Council, which in all probability will be held in London next October.

A Sub-Committee will shortly be appointed to deal with the classification of electrical machinery and apparatus—that is to say, to undertake all practical questions. One of the first points to which they are likely to turn their attention is the question of "Standards of Light," and, with the co-operation of the other Electrotechnical Committees, it is hoped that a satisfactory decision may in due course be arrived at.

City and Guilds of London Institute—Examinations in Wiremen's Work.

An Advisory Committee was appointed in 1906 by the City and Guilds of London Institute to revise their syllabus for examination in electrical wiremen's work, to which Committee the Council was invited to nominate representatives. Mr. James Swinburne, F.R.S., Past President, and Mr. W. H. Patchell, Member of Council, were accordingly asked to act, and subsequently representations were made to the Council by that Institute that they were of opinion that considerable encouragement would be given to electric wiremen in raising their trade status if the Council could see its way to permit recognition by the Institution of Electrical Engineers of the City and Guilds certificates. As it was felt that such co-operation of the Institution in the matter would be advantageous to the industry generally, the proposal was favourably entertained, and it was agreed, subject to approval of the syllabus of instruction, to give assistance this year by appointing qualified persons to represent the Institution and attend the practical examinations. The following members very kindly agreed to give their services on behalf of the Institution and to furnish a short report on the manner in which the candidates performed the practical part of their work :—

London Centres—
Woolwich, P. R. Friedlaender.
Mile End Rd., Dr. J. Henderson.
East Ham, A. H. Seabrook.
West Ham, W. T. Maccall.
Poplar, J. H. Bowden.
Clerkenwell, V. A. Mundella.
Borough Road, J. T. Morris.
Battersea, F. A. Bond.
Chelsea, P. Still.
Chiswick, A. W. Money.

London Centres (*continued*)—
Paddington, W. R. Rawlings.
South Tottenham, G. H. Baker.
Wimbledon, H. Tomlinson-Lee.
Kilburn, J. E. Pownall.
Highgate, Dr. C. V. Drysdale.
Barnsley, E. A. Barker.
Bath, S. F. Walker.
Belfast, R. Stanley.
Birmingham, Dr. W. E. Sumpner.
Blackburn, P. P. Wheelwright.

Bolton, A. A. Day.
Brighton, C. B. Smith.
Bristol, Professor A. P. Chattock.
Cork, H. G. Whiting.
Croydon, A. C. Cramb.
Darlington, E. Cox-Walker.
Derby, W. C. Goodchild.
Dublin, T. Tomlinson.
Enfield, H. H. Perry.
Huddersfield, A. B. Mountain.
Kingston, J. E. Edgcome.
Lancaster, W. A. Tester.
Leeds, H. Dickinson.
Manchester, E. S. Bradburne.
Norwich, F. M. Long.
Peterboro', G. H. Hardwick.
Plymouth, E. G. Okell.
Portsmouth, B. Handley.
Redhill, A. W. Makovski.
Rotherham, G. Young.
Runcorn, A. Lester Taylor.
Salford, A. Kelly.
Sheffield, E. H. Crapper.
Tonbridge, Horace Boot.
Wolverhampton, H. A. Howie.

To all of these members the Council desires to express its acknowledgments of the valuable services they have been good enough to render to the Institution in this respect.

"Science Abstracts."

In the work of publishing *Science Abstracts* the Committee has continued to receive the assistance and financial support of the Physical Society of London. The American Institute of Electrical Engineers and the American Physical Society have also again given valuable assistance in distributing the periodical among their members and in bringing it prominently to their notice. This year the Associazione Elettrotecnica Italiana has also joined in supporting the publication by promoting the circulation of it among their members, to whom there has been granted a special subscription rate, in return for which the Italian Society has kindly offered a similar concession to the members of the Institution in respect of its own *Transactions.*

In 1907, 2,132 and 1,474 abstracts were published in the two sections, "Physics" and "Electrical Engineering' respectively (1,296 pages in all). The usefulness of the publication is shown by the fact that the amount realised by sales to the public and members of other Institutions, apart from members of this Institution and of the Physical Society, was £487.

Other Work of the Institution.

The Council was recently informed by the Army Council that the War Office proposed to establish Electrical Engineering Corps for attachment to the Territorial Army at certain centres in the United Kingdom, and the Institution was invited to co-operate with the County Associations in finding officers with electrical engineering qualifications to command these units. The Council is at present in communication with the County Associations on the matter.

A request was received in the course of last year from the Executive Committee of the Franco-British Exhibition to assist in organising an Electrical Section in connection with the Engineering and Shipping

Group of the Exhibition. The Electricity Supply Companies of London have agreed, subject to satisfactory support for the scheme being forthcoming, to give financial assistance, and they have undertaken the responsibility of organising a collective electrical exhibit in the Machinery Hall.

Presentations from Other Societies.

In courteous recognition of the reception and entertainment of their members on the occasion of the visit of kindred institutions in the summer of 1906, the American Institute of Electrical Engineers has presented to the Institution a bronze bust of Benjamin Franklin. The presentation took place with due ceremony at the Ordinary General Meeting of April 30th, and was made on behalf of the American Institute by Mr. H. F. Parshall, M.I.E.E., their Honorary Secretary for Great Britain.

The Société Internationale des Electriciens has also expressed with great courtesy its appreciation of the hospitality granted to its members on the same occasion by presenting through its President, Monsieur Henri Becquerel, a gold medal bearing on its obverse a head of André Marie Ampère, and on the reverse the names of the two Institutions and the date at which the visit took place.

The Council is greatly gratified at the kind manner in which the American Institute and the French Society have expressed their acknowledgments of their recent reception by their British colleagues.

Museum.

Space has now been provided at the Institution for the temporary accommodation of the articles collected for the Museum. Some valuable apparatus and objects of historical interest have been accumulated, due chiefly to the generosity of members and firms interested, and a committee is now in charge of the work of classifying and arranging the articles. It is hoped that members will assist in creating a museum worthy of the Institution by presenting apparatus of historical interest or by advising the Council of the existence of such.

Benevolent Fund.

The Committee of Management reports that the Benevolent Fund of the Institution shows a satisfactory increase for the past year. On December 31, 1907, the capital account of the Fund stood at £2,755 9s. 11d., as compared with £2,532 16s. 4d. at the end of 1906. The donations to the Fund in 1907 include one of £52 10s. from the Western Electric Company, and another of £37 from the Committee of the Electrical Engineers' Ball. In January of the present year a special appeal was sent to all members of the Institution, with the gratifying result that the capital account of the Fund has since the new year been increased to over £3,000. The special donations

since the new year in answer to this appeal, which have not been taken account of in the balance sheet for the year under consideration, include one of 100 guineas from Mr. W. B. Esson (Member). With their accustomed generosity the Committee of the Electrical Engineers' Ball have given a further donation of £75 to the Fund, this being their surplus from this year's Ball. The Council desire to acknowledge their indebtedness to the generosity of these and other donors and subscribers who have kindly continued to support the Fund.

Four grants in aid were made during the year under the rules of the Committee.

The Wilde Benevolent Trust Fund stands at £1,744 16s., and one grant in aid has also been made from the income of this Fund in 1907.

Annual Accounts.

The Report of Mr. Robert Hammond, the Hon. Treasurer, shows that the balance carried to the General Fund at the end of 1907, being excess of income over expenditure, was £3,678 9s. 2d., as compared with £3,548 15s. for 1906, the increase for 1907 being £129 14s. 2d.

Balance Sheet.—The balance sheet sets out the total investments other than the investments of the Trust Funds. It will be seen that the total assets amount to £46,358 16s. 8d., against which are to be set liabilities amounting to £1,046 2s. 5d., leaving as the net assets of the Institution £45,312 14s. 3d.

The investments in stocks and shares included in the above appear in the accounts at cost price with a book value of—

	£	s.	d.
Life Compositions	5,555	12	0
Entrance Fees...	3,719	12	11
Building Fund	1,940	15	3
General Fund	12,042	7	9
	£23,258	7	11

and their value at the current market prices on April 30th was £20,890.

Trust Funds.—No alteration has taken place in these three Funds during the year under consideration.

Life Compositions.—No alteration has taken place in this Fund during the year under consideration, and it still stands, as reported last year, at £5,581 13s.

Entrance Fees Fund.—It will be noticed that the Fund has increased during the year by £587 11s., and that the total of the Fund now stands at £4,455 2s. 6d.

Building Fund.—It will be noticed that the Fund has increased during 1907 by the amount of £643 9s. 1d., the increase being due to revenue from property, subscriptions, and sundry other items.

Out of the available balance of £2,114 15s. 4d., there has been invested during the year on account of this Fund—

	£	s.	d.
£1,000 South-Eastern Railway 5 per cent. Debenture Stock	1,447	1	9
£550 Manchester Corporation 3 per cent. Stock	493	13	6
	£1,940	15	3

General Fund.—This Fund has increased to the extent of £3,678 9s. 2d., and now stands at £13,900 6s. 4d. The investments on account of this Fund during the year were as follows:—

	£	s.	d.
£1,500 Great Central and Midland Railway 3½ per cent. Guaranteed Stock... ...	1,568	8	9
£1,200 Consols, 2½ per cent.	1,035	1	0
	£2,603	9	9

It will be noticed that, for the first time, a note has been introduced into the balance sheet showing how the balance of the General Fund is made up.

Library.—This year's account shows for the first time the amount of the unexpended portion of the Library Grant.

Summary.—The increases of the Funds during the year are as follows:—

	£	s.	d.
Entrance Fees...	587	11	0
Building Fund	643	9	1
General Fund	3,678	9	2
	£4,909	9	3

LIBRARY.

Under the supervision of the Library Committee the work of re-organising the Library makes satisfactory progress. It will be remembered that in 1905 the re-organisation was actively taken in hand by a sub-committee, which reported upon the state of the Library and recommended the acquisition of a number of books, in order to complete the Institution's collection of electrotechnical literature up to date as far as possible. The list contained the titles of 1,623 works, dating for the most part between 1885 and 1905, with a few earlier references. The Council made a special grant of money for the purchase of these books, of which up to the present 1,162 have been acquired. In addition to these the number of new books purchased since June 1, 1907, is 142, and 186 books and pamphlets have been presented by members, publishers, and kindred societies. The Council is pleased to note that in consequence of the extended resources of the Library, due to the efforts of the Library Committee, the number of members who consult it has very considerably increased during the

last year, which may be regarded as a satisfactory indication of its usefulness to them as a library of reference. The total number of readers during the past twelve months has been 640. Permission to use the Library has been given to Members of the Association of Engineers-in-Charge.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, ETC., RECEIVED BY THE INSTITUTION.

BRITISH.

Cambridge Philosophical Society, Proceedings.
Chartered Institute of Patent Agents, Transactions.
Civil and Mechanical Engineers' Society, Transactions.
Faraday Society, Transactions.
Greenwich Magnetical and Meteorological Observations.
Institute of Chemistry, Proceedings.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland, Transactions.
Institution of Mechanical Engineers, Proceedings.
Institution of Naval Architects, Transactions.
Iron and Steel Institute, Journal.
Liverpool Corporation Tramways, Annual Reports.
Liverpool Engineering Society, Proceedings.
Manchester Literary and Philosophical Society, Memoirs and Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Reports.
North-East Coast Institution of Engineers and Shipbuilders, Transactions.
North of England Institute of Mining and Mechanical Engineers' Transactions.
Physical Society, Proceedings
Röntgen Society, Journal.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Quarterly Journal.
Royal Scottish Society of Arts, Transactions and Journal.
Royal Society, Philosophical Transactions and Proceedings.
Royal Society of Arts, Journal.
Royal Society of Edinburgh, Transactions and Proceedings.
Royal Society of Victoria, Proceedings.
Royal United Service Institution, Journal.

Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors' Institution, Transactions and Professional Notes.
Tramways and Light Railways' Association, Official Circular.

COLONIAL.

Canadian Society of Civil Engineers, Transactions.
Engineering Association of New South Wales, Proceedings.
Engineering Society of Toronto, Transactions.
Indian Telegraph Department, Administration Reports.
South Australia, Meteorological Observation Reports.
Nova Scotia Institute of Science, Transactions and Proceedings.

AMERICAN.

American Academy of Arts and Sciences, Proceedings.
American Institute of Electrical Engineers, Transactions and Proceedings.
American Institute of Mining Engineers, Transactions and Bi-Monthly Bulletin.
American Philosophical Society, Proceedings.
American Society of Civil Engineers, Proceedings.
American Society of Mechanical Engineers, Transactions and Proceedings.
Bureau of Standards, Washington, Bulletin.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
Ordnance Department of the United States, Notes.
Philadelphia Electrical Bureau, Annual Reports.
Smithsonian Institution, Reports, Miscellaneous Collections and Contributions to Knowledge.
U.S. Official Patent Gazette.
Western Society of Engineers, Journal.

AUSTRIAN.

Kaiserliche Akademie der Wissenschaften, Wien, Sitzungsberichte.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électrotechnique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.
Koninklijke Akademie van Wetenschappen, Amsterdam, Proceedings.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Bureau des Longitudes, Annuaire.
Société des Anciens Élèves des Écoles Nationales d'Arts et Metiers, Bulletin Technologique.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Physikalische Technische Reichsanstalt, Abhandlungen.
Schiffbautechnische Gesellschaft, Jahrbuch.
Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.
Reale Accademia dei Lincei, Atti e Memorie.

JAPANESE.

College of Science and Engineering, Kyōto Imperial University, Memoirs.

RUSSIAN.

Section Moscovite de la Societé Impériale Technique Russe.

SWEDISH.

K. Svenska Vetenskaps-Akademien, Arkiv för Matematik, etc.

SWISS.

Association Suisse des Électriciens, Annuaire.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Automobile Owner.
Cassier's Magazine.
Central.
Civil Engineering.
Electrical Bulletin.
Electrical Engineer.

Electrical Engineering.
Electrical Industries.
Electrical Magazine.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Engineer.
Engineering.
Engineering Magazine.
Engineering Review.
Engineering Times.
English Mechanic.
Illuminating Engineer.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
International Marine Engineering.
Iron and Coal Trades Review.
Light Railway and Tramway Journal.
Mechanical Engineer.
Mining Journal.
National Telephone Journal.
Nature.
Page's Weekly.
Philosophical Magazine.
Post Office Electrical Engineers' Journal.
Railway Times.
Royal Engineers' Journal.
Tramway and Railway World.
Vulcan.
World's Work.

AMERICAN.

American Journal of Science.
American Telephone Journal.
Electric Journal.
Electrical Review.
Electrical World.
Electrochemical and Metallurgical Industry
Engineering News.
India Rubber World.
Journal of Electricity, Power and Gas
Journal of the Telegraph.
Physical Review.

Scientific American.
Street Railway Journal.
Technology Quarterly.
Terrestrial Magnetism and Atmospherical Electricity.
Western Electrician.

AUSTRIAN.

Elektrotechnik und Maschinenbau.

DANISH.

Teknisk Tidsskrift.

DUTCH.

De Ingenieur.

FRENCH.

Archives des Sciences Physiques et Naturelles.
Électricien.
Houille Blanche.
Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Lumière Électrique.
Mois Scientifique et Industriel.
Portefeuille Économique des Machines
Revue Électrique.

GERMAN.

Annalen der Elektrotechnik.
Annalen der Physik und Chemie.
Annalen der Physik und Chemie, Beiblätter.
Centralblatt für Accumulatoren und Elementenkunde.
Elektrische Kraftbetriebe und Bahnen.
Elektro-Ingenieur Kalender (Hirsch und Wilking).
Elektrotechnische und Polytechnische Rundschau.
Elektrotechnische Zeitschrift.
Elektrotechnischer Anzeiger.
Fortschritte der Elektrotechnik.
Glückauf.
Jahrbuch der Elektrochemie.
Physikalische Zeitschrift.
Sammlung Elektrotechnischer Vorträge.

Technische Literatur.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricista
L'Elettricita.
Giornale del Genio Civile.
Il Nuovo Cimento.

SIAMESE.

Siam Engineering.

SPANISH.

La Ingenieria.

SWISS.

Schweizerische Elektrotechnische Zeitschrift.

The Institution of

STATEMENT OF INCOME AND

ENDED 31st

Dr.

EXPENDITURE.

								£	s.	d.	£	s. d.
To Management :—												
Salaries								1,797	10	0		
Retiring Allowance								300	0	0		
Accountants' Fees								21	0	0		
Printing, Stationery, and Addressing ...								495	19	10		
Postage								839	2	10		
Telephone								26	10	0		
Travelling								153	19	4		
											3,634	2 0
„ Rent, Insurance, Lighting, and Firing ...								...		...	670	3 11
„ Publications :—												
Journal								1,628	17	2		
"Science Abstracts"—												
Disbursements ...					...£1,738	10	1					
Less Receipts ...					... 1,360	11	7					
								377	18	6		
											2,006	15 8
„ Meetings :—												
Advance Proofs, Refreshments, &c.								163	8	5		
Reporting								65	2	0		
											228	10 5
„ Local Sections								...		...	582	15 6
„ Premiums								...		...	146	2 5
„ International Electrotechnical Commission ...								...		...	169	19 6
„ Conversazione								...		...	298	18 6
„ Depreciation :—												
Library (10 %)								166	11	10		
Furniture (5 %)								22	18	0		
											189	9 10
„ Miscellaneous Expenses								...		...	105	0 4
„ Balance carried to General Fund, being excess of Income over Expenditure								...		...	3,678	9 2
											£11,710	7 3

Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1907.

Cr.

INCOME.

	£ s. d.	£ s. d.
By Subscriptions	...	... 10,441 17 4
„ Dividends on Investments :—		
Life Compositions Fund	£173 11 5	
General and Entrance Fees Funds	490 15 2	
		664 6 7
„ Interest on Cash on Deposit		30 2 4
„ Journal :—		
Sales	201 17 7	
Advertisements	357 0 0	
		558 17 7
„ Wiring Rules		9 17 5
„ Model General Conditions for Contracts		5 6 0

£11,710 7 3

BALANCE SHEET,

Dr.

LIABILITIES.

			£ s. d.
To Salomons Scholarship Trust Fund (Income)			28 19 2
„ David Hughes Scholarship Trust Fund :—			
Capital uninvested	1 5 0		
Income	13 13 7		
			14 18 7
„ Wilde Benevolent Trust Fund (Income)...			87 18 6
„ Life Compositions Fund			5,581 13 0
„ Entrance Fees Fund			4,455 2 0
„ Building Fund			21,375 12 5
„ Sundry Creditors			782 18 6
„ Local Sections :—			
Due to Hon. Sec. Newcastle Section			2 14 8
„ Subscriptions received in advance			89 3 0
„ Foreign Visit Fund			39 10 0
„ General Fund			13,900 6 4

ROBERT HAMMOND,
Honorary Treasurer.

G. C. LLOYD,
Secretary.

£46,358 16 8

We beg to report that we have examined the above Balance Sheet and have inspected the Bankers' Certificates of Investments and the Title Deeds and the Balance Sheet is properly drawn up so as to exhibit a true its books. We hereby certify that all our requirements as Auditors have

ALLEN, BIGGS & CO.,
Chartered Accountants.
147, Leadenhall Street, E.C.

May 1, 1908.

31st DECEMBER, 1907.

Cr.

ASSETS.

				£	s.	d.
By Life Compositions Investments (at cost)				5,555	12	0
„ Entrance Fees Investments „				3,719	12	11
„ Buildings and Building Site „				19,260	17	1
„ Building Fund Investments „				1,940	15	3
„ General Fund Investments „				12,042	7	9
„ Sundry Debtors				1,025	7	11
„ Local Sections :—						
Cash in hands of Hon. Sec. Birmingham Section	2	18	7			
do. do. do. Dublin do.	3	17	2			
do. do. do Glasgow do.	8	3	3			
do. do. do. Leeds do.	17	0	1			
do. do. do. Manchester do.	8	1	10			
				40	0	11
„ Furniture				435	1	10
„ Library				1,499	6	7
„ Vellum Diploma Forms				3	18	9
„ Cash :—At Bankers'	643	12	1			
Petty Cash	105	17	1			
P. O. Savings Bank	86	6	6			
				835	15	8
				£46,358	16	8

Statements of Account with the Books and Vouchers of the Institution. We of the Tothill Street Property. In our opinion the Statements are correct, and correct view of the state of the affairs of the Institution as shown by been complied with.

H. ALABASTER,
SIDNEY SHARP, } *Honorary Auditors.*

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholar in 1907	50	0	0
„ Balance carried to Balance Sheet	28	19	2
	£78	19	2

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1907...	75	0	0
Balance carried to Balance Sheet	13	13	7
	£88	13	7

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,744	16	0
	£1,744	16	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Grant made in 1907	25	0	0
„ Balance carried to Balance Sheet	87	18	6
	£112	18	6

TRUST FUND.

	Cr. £ s. d.
By Investments (at cost) :—	
£1,500 New South Wales 3½ % Stock	1,556 5 9
500 Cape of Good Hope 3½ % Stock	570 13 6
	£2,126 19 3

TRUST FUND (Income).

	Cr. £ s. d.
By Balance (as per last Account)	9 17 8
„ Dividends received in 1907	69 1 6
	£78 19 2

TRUST FUND.

	Cr. £ s. d.
By Investment (at cost) :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,008 15 0
„ Balance uninvested carried to Balance Sheet	1 5 0
	£2,000 0 0

TRUST FUND (Income).

	Cr. £ s. d.
By Balance (as per last Account)	28 3 7
„ Dividends received in 1907	60 10 0
	£88 13 7

TRUST FUND.

	Cr. £ s. d.
By Investments (at cost):—	
£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493 16 3
£215 North Eastern Railway 4 % Guaranteed Stock ...	250 19 9
	£1,744 16 0

TRUST FUND (Income).

	Cr. £ s. d.
By Amount (as per last Account)	50 14 6
„ Dividends received in 1907	51 9 3
„ Interest do. do.	1 14 9
	£112 18 6

LIFE

Dr.

	£	s.	d.
To Amount (as per last Account)	5,581	13	0
	£5,581	13	0

ENTRANCE

Dr.

	£	s.	d.
To Amount (as per last Account)	3,867	11	6
„ „ received in 1907	587	11	0
	£4,455	2	6

COMPOSITIONS.

Cr.

	£	s.	d.
By Investments (at cost) :—			
£318 0 0 Cape of Good Hope 4 % Consolidated Stock	306	0	0
1,679 19 5 India 3½ % Stock	1,776	5	0
120 0 0 South-Eastern Railway 5 % Debenture Stock	204	16	6
355 5 10 Canada 3 % Stock	352	13	6
289 17 4 Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10
6 0 0 East Indian Railway Class "C" Annuity ...	185	1	9
87 0 0 Great Eastern Railway 4 % Consolidated Preference Stock	130	15	2
175 0 0 Great Eastern Railway 4 % Debenture Stock	251	5	5
5 6 4 Great Indian Peninsula Railway "B" Annuity	133	17	6
190 13 4 Metropolitan Water Board "A" Stock ...	207	17	9
520 0 0 Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3
200 0 0 Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0
29 0 0 Madras Railway 5 % Stock	44	9	4
60 0 0 South Indian Railway 4½ % Debenture Stock	88	1	4
30 0 0 Burma Railway Co.'s Stock	30	12	3
40 0 0 East Indian Railway 4½ % Debenture Stock ...	57	3	7
400 0 0 Natal Zululand Railways 3 % Debentures ...	351	1	0
350 0 0 New Zealand 3½ % Inscribed Stock	345	12	10
	£5,555	12	0
„ Balance	26	1	0
	£5,581	13	0

FEES.

Cr.

	£	s.	d.
By INVESTMENTS (at cost) :—			
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	1,200	0	0
918 3 2 India 3½ % Stock	973	17	10
410 0 0 East Indian Railway 4½ % Debenture Stock ...	586	1	7
800 0 0 North Eastern Railway 4 % Preference Stock ..	959	13	6
	£3,719	12	11
„ Balance	735	9	7
	£4,455	2	6

Dr

	£	s.	d.
To Amount (as per last Account)	20,732	3	4
„ Revenue from Property	549	1	5
„ Subscriptions	64	11	4
„ Dividends	23	15	0
„ Surplus from Vellum Diplomas	6	1	4
	£21,375	12	5

FUND.

Cr.

	£	s.	d.
By Buildings and Building Site, 15 to 18, Tothill Street (as per last Account)	19,260	17	1
„ Investments (at cost) :—			
£1,000 South-Eastern Railway 5 % Debenture Stock 1,447 1 9			
550 Manchester Corporation 3 % Stock ... 493 13 6			
	1,940	15	3
„ Balance	174	0	1
	£21,375	12	5

GENERAL

Dr.

	£	s.	d.
To Amount (as per last Balance Sheet)	10,221	17	2
Add Excess of Income over Expenditure for 1907	3,678	9	2
	£13,900	6	4

FUND.

Cr.

		£ s. d.
By INVESTMENTS (at cost) :—		
£52 13 8 Great Indian Peninsula Railway "B" Annuity	1,239 17 9	
721 0 0 Madras Railway 5% Stock ...	1,114 14 0	
623 0 0 Great Western Railway 5% Preference Stock	999 18 1	
2,200 0 0 Natal Zululand Railways 3% Debentures	1,919 11 0	
650 0 0 New Zealand 3½% Inscribed Stock	641 18 2	
1,100 0 0 Great Eastern Railway 4% Consolidated Preference Stock ...	1,266 18 9	
1,050 0 0 London and North Western Railway 4% Preference Stock ...	1,225 4 9	
700 0 0 Great Eastern Railway Metropolitan 5% Guaranteed Stock ...	1,030 15 6	
		9,438 18 0
„ INVESTMENTS DURING 1907 :—		
£1,500 0 0 Great Central and Midland Railway 3½% Guaranteed Stock ...	1,568 8 9	
1,200 0 0 Consols 2½%...	1,035 1 0	
		2,603 9 9
		12,042 7 9
„ Balance		1,857 18 7

The above balance is made up as follows :—

ASSETS.		
Sundry Debtors	1,025 7 11	
Cash in Hand	875 16 7	
Furniture	435 1 10	
Library	1,499 6 7	
Vellum Diploma Forms ...	3 18 9	
		3,839 11 8
LIABILITIES.		
Uninvested Balances of Special Funds	1,106 16 11	
Sundry Creditors	785 13 2	
Subscriptions in Advance	89 3 0	
		1,981 13 1
		£1,857 18 7

£13,900 6 4

LIBRARY.

Dr.

	£	s.	d.
To Amount (as per Balance Sheet)	1,499	6	7
	£1,499	6	7

LIBRARY.

Cr.

	£	s.	d.
Outlays on Books, Pictures up to December 31, 1906	1,763	9	8
Less Provision for Depreciation (1901–6)	479	13	10
As per last Balance Sheet	1,283	15	10
Grant in 1906 (Balance expended in 1907) £25 19 0			
„ in 1907 (current)... 150 0 0			
„ in 1907 (special) 350 0 0			
525 19 0			
Less Expenditure on Furniture, &c. ... £17 10 7			
Unexpended portions of 1907 Grants... 126 5 10			
143 16 5			
Net Expenditure on Books and Binding in 1907	382	2	7
	1,665	18	5
Less 10% Depreciation for 1907	166	11	10
	£1,499	6	7

The PRESIDENT, having read the Report of the Council in brief abstract, begged leave to move: "That the Annual Report of the Council as presented be received and adopted, and that it be printed in the *Journal* of the Proceedings."

Mr. T. CUSHING seconded the motion, which was then put to the meeting and carried unanimously.

The PRESIDENT: I will now read the Auditor's Certificate as to the correctness of the accounts: "We beg to report that we have examined the above Balance Sheet and Statements of Account with the books and vouchers of the Institution. We have inspected the Bankers' Certificates of Investments and the Title Deeds of the Tothill Street property. In our opinion the statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the affairs of the Institution as shown by its books. We hereby certify that all our requirements as auditors have been complied with." I now move: "That the Statement of Accounts and the Balance Sheet for 1907, copies of which have been sent to the members with the Notice convening the meeting, be taken as read, and that they be received and adopted."

Mr. F. H. NALDER having seconded the resolution, it was then put to the meeting and carrried unanimously.

Mr. W. H. PATCHELL: Mr. President and Gentlemen, for another year we have led, and probably for a few years still we shall lead, a nomadic life. The Institution of Civil Engineers is very good to us during the winter; when it closes its doors the Society of Arts takes pity on us. But how long is this sort of thing to go on? Is it not time that the Institution began to take more serious steps to obtain a home of its own? It is an open secret that the site of the Institution of Civil Engineers will soon be covered by new Government buildings, and that the eviction which has been hanging over their heads for several years will now take place. I have no doubt that they will, in their new home, be as kind to us as they have been in their present home; but as we get larger and larger it does seem more important that we should, if possible, take steps to have a permanent home of our own. If the question was warmly taken up by the members I think that might be a realised fact. We have a Building Fund which, due to the flux of time, is getting larger and larger. Subscriptions do not come in as fast as they might, in exactly the same way as the President has said that the Benevolent Fund is neglected. But no fund will be subscribed to very largely if it is not taken up warmly. But this does not at all detract from our gratitude to those who up to the present have extended their hospitality to us, and I therefore move: "That the best thanks of the Institution be, and are hereby accorded to the Council of the Institution of Civil Engineers, the Council of the Institution of Mechanical Engineers, and to the Council of the Royal Society of Arts for the great courtesy extended to the Institution of placing their rooms at its disposal for the holding of its General Meetings."

Mr. F. GILL: Mr. President and Gentlemen, I have much pleasure

in seconding the vote of thanks that Mr. Patchell has proposed, and I desire particularly to allude to the services rendered to us by the Institution of Civil Engineers. It has undoubtedly been a tremendous advantage to us to be associated in the way we have been with the premier engineering institution of the world. Nothing could have exceeded their generosity in the way they have met us and offered us accommodation. As the time approaches when we are getting nearer and nearer to having a building of our own, I am sure we shall look back on the conduct of the Institution of Civil Engineers with greater appreciation. I have much pleasure in seconding the vote of thanks.

The resolution was put and carried unanimously.

Mr. S. SHARP: I beg to move: "That the best thanks of the Institution are given to the Local Honorary Secretaries and Treasurers abroad for their kind services during the past year." It gives me great pleasure to propose that motion because the Honorary Secretaries and Treasurers abroad greatly help the Institution by bringing in additional members, and by keeping those who are already members in touch with the mother country and the Institution.

Mr. T. MATHER, F.R.S.: I have much pleasure in seconding the motion.

The resolution was put and carried unanimously.

Mr. A. CAMPBELL SWINTON: I have much pleasure in moving the next resolution: "That the best thanks of the Institution be tendered to Messrs. Bristows, Cooke and Carpmael for their kind services in their capacity of Honorary Solicitors to the Institution during the past year." I believe as a matter of fact in the past year we have not required to trouble our Honorary Solicitors very much, but in previous years they have done a very large amount of work for us, and I understand that in the present year we also propose to give them a considerable amount of work, so that our gratitude on this occasion may be a foretaste of favours to come.

Mr. T. CUSHING having seconded the resolution, it was put and carried unanimously.

Mr. J. E. KINGSBURY: I have pleasure in moving: "That the best thanks of the Institution be given to Mr. Robert Hammond in recognition of the valuable services rendered by him as Honorary Treasurer of the Institution during the past session." The services of Mr. Hammond are fairly obvious to all the members, but I doubt whether any members other than those who serve on the Finance Committee are able to estimate the ability which he brings to bear in the service of the Institution, and the industry and acumen which he displays in his office as Honorary Treasurer. Our warm thanks are undoubtedly due to him, and I have much pleasure in moving the resolution.

Mr. H. HUMAN: I have much pleasure in seconding the motion. As one of the junior members of the Council, and having been behind the scenes, I am in a position to testify to the splendid services that

Mr. Hammond has rendered to the Institution, not only as Treasurer, but also on the Council and various Committees. Mr. Hammond's long acquaintance with the inner working of the Institution has made him almost indispensable to us, and I feel that in addition to the services he renders us as our Finance Minister, we also have to thank him for his splendid services on the Council and the various Committees. I have much pleasure in seconding the motion.

The resolution was put and carried unanimously.

Mr. W. B. Esson: I have much pleasure in proposing: "That the best thanks of the Institution be accorded to the Honorary Auditors, Mr. H. Alabaster and Mr. Sidney Sharp, for their kind services during the past year." That we appreciate these services highly is shown by the fact that these gentlemen have been elected to perform the same services next year. Hard work seems to agree with them.

Mr. C. LeMaistre having seconded the resolution, it was put and carried unanimously.

The President: I have now to announce that the new Council and the Honorary Officers for the year 1908–1909 are duly elected, and to state that as no candidates other than those nominated by the Council have been put forward, the new nominees of the Council are now duly elected in accordance with the Articles of Association. The new officers are:—

President.

W. M. Mordey.

Vice-Presidents.

F. Gill.
Col. H. C. L. Holden, R.A., F.R.S.
Dr. G. Kapp.
C. P. Sparks.

Members of Council.

S. Evershed.
H. E. Harrison, B.Sc.
Dr. E. Hopkinson.
J. W. Jacomb-Hood.
J. E. Kingsbury.
T. Mather, F.R.S.
M. O'Gorman.
Major W. A. J. O'Meara, C.M.G.
G. W. Partridge.
W. H. Patchell.
W. Rutherford.
Professor A. Schwartz.
J. F. C. Snell.
G. Stoney.
A. A. C. Swinton.

Associate Members of Council.

J. Hunter Gray.
H. Human.
J. E. Taylor.

Honorary Treasurer.

Robert Hammond.

Honorary Auditors.

H. Alabaster.
Sidney Sharp.

The meeting then terminated.

A Special General Meeting of Members, Associate Members, and Associates, duly convened and held in the Lecture Theatre of the Medical Examination Hall, Victoria Embankment, London, W.C., on Tuesday, June 30, 1908. Colonel R. E. B. CROMPTON, C.B., President, in the chair.

The SECRETARY read the notice convening the meeting as follows :—

June 23, 1908.

Notice is hereby given that a Special General Meeting of Members, Associate Members, and Associates of the Institution will be held in the Lecture Theatre of the Medical Examination Hall, Victoria Embankment, W.C., on *Tuesday, the 30th day of June*, at half-past five o'clock in the afternoon, for the purpose of considering, and, if approved, of passing the following resolution, namely :—

"That the purchase of the lease of the site and building known as 'The Medical Examination Hall,' situate on the Victoria Embankment, W.C., now the property of the Royal College of Physicians of London and the Royal College of Surgeons of England, for the sum of £50,000, be sanctioned and approved, and that the Council be authorised to sell such of the investments of the Institution and to make such other financial arrangements (including the disposal of the site in Tothill Street now owned by the Institution) as the Council may consider necessary for the above purpose."

The PRESIDENT : Gentlemen, we are met here to consider the momentous question of providing a permanent home for the Institution. After years of saving for our Building Fund, we have at last an opportunity of securing for ourselves a building which we believe is eminently suited for the purposes of the Institution. With your permission, I will first call upon your Hon. Treasurer, Mr. Hammond, who will give you the figures on which we depend to enable you to form your decision to-day ; and afterwards I will call upon Mr. Mordey, who has devoted much time and attention to this matter, to give you the history of the affair. The President.

Mr. Hammond.

Mr. ROBERT HAMMOND: From the notice which has been circulated the members will see that the purchase of the buildings is proposed at a sum of £50,000, the amount being payable upon possession on the 1st June next. I may say that that date has been fixed upon for the purpose of giving us another twelve months' funds to assist us in coping with the financial part of the operation. The actual payment for the buildings will be £50,000. I say "buildings," because some members may like to know that we are really dealing with two buildings. The first building that was put up was a building in the front separated from this back building by the corridor; and then, some two years later, the building at the back, including the theatre, was added. I mention that because some have thought that we were only going to buy the one building in the front.

Capital Requirements.—The question of what is to be done with the theatre may not engage our attention immediately, but in order that we may be on the safe side, I add to the £50,000 actual liability a concurrent liability of £6,000. The £6,000 is the "estimated cost of enlargement of theatre, six months' rent of old premises, removal, painting, new furniture, and new bookshelves," bringing our total responsibilities to a sum of £56,000.

Capital Resources.—Our trustee investments are: Life Compositions Fund, £5,555; Entrance Fees Fund, £3,719; Building Fund (excluding the value of the site in Tothill Street), £1,940; and General Fund, £12,042, giving a grand total of Trustee Investments of £23,256. It will be noticed that, included in that sum, there is £5,555, being the first item under the head of "Life Compositions Fund." By the Articles of Association the Institution is compelled to keep intact monies paid by members in respect of life compositions, and those sums must be invested. Dealing with it on that basis, there is left a sum of £17,701 actually invested in Trustee Securities, as shown by our last accounts. Since those accounts were published the Council have transferred to the Kelvin Lecture Fund, which they thought it proper to form on the death of our late President, £1,000 in Consols, which cost £862, leaving a total of £16,839, which we can convert into cash at any moment. This £16,839 has taken some years to accumulate, and since its investment it has suffered a depreciation, which is apparently common in most securities in the financial world. Therefore we include the value in this statement, not at £16,839, but at their estimated realisable value of £15,000. Since accounts for 1907 were published, investments to the amount of £4,000 have been made, which can be realised at that sum, and by this time next year, when we would have to pay for the building, we should have a further increment from the natural growth of the Institution funds, without counting anything for an increase in the number of members, of £4,000; so that this day twelve months we ought to have available £23,000. Our Tothill Street site stands in our books at £19,260. We are advised that it has appreciated in value, but for the purpose of this statement we deal with it as a book value of £19,260, which gives us a total of £42,260, and a liability of £56,000.

I therefore add to the £42,260 an amount to be raised on loan of £16,000, making a total of £58,260. Following the custom of various Chancellors of the Exchequer, as I hold an analogous position at this Institution, I have ventured to add up the resources at £2,300 more than the requirements, for the purpose of having that amount to hand from the start. In dealing with the liability before us, it is wise not to cut matters too fine, but to have a couple of thousand pounds in hand. Having, then, dealt with the question from the capital point of view, I now deal with it from that of income and expenditure. Mr. Hammond.

Income.—The subscriptions, as set forth in the 1907 accounts, amounted to £10,441. The £10,441 which appears in the statement was, of course, that for last year, and this should be enhanced by this year's increment and by the increment up to June next year. I therefore take this item into the account as £11,041. Then, if we preserve our Life Compositions investment of £5,500, we should have to the credit the £173, which is the amount of interest that comes to us thereon in the shape of dividends. Then the sales and advertisements from the *Journal* I take at the same figure as they appeared in 1907, £558; the Entrance Fees I have ventured to increase by £100; and then there is the rental of £650 which would accrue to us from a portion of this building which is already let. So that the total of our income for 1909 would be £13,109.

Liabilities.—That, I must say, forms the serious part of this proposition, because our expenditure, which last year stood at £8,182, including £150 which we voted to the Library, will be increased in this building to £12,953, the increase being first an increased expenditure in the new building. There are also the rates and taxes, which come to £1,670; the ground rent is £2,201, and there is a very proper provision for an Amortisation Fund, the effect of which would be to wipe off the £50,000 during the period of the lease, which is brought in at £200, giving a total of £12,953. Then, if we are going to borrow £16,000, we shall have to pay interest upon it, and in order not to disappoint anybody, I have put the interest down at 4 per cent., though it would be our endeavour to borrow it on better terms than that. As a matter of fact, I have put it down at a sum at which the money could be borrowed at any moment. And, until the Tothill Street site is sold, there would be an extra sum, because we should have to borrow a sum which would be increased to the extent of the value of the Tothill Street site, say at 3½ or 4 per cent., whereas the Tothill Street site does not bring us in quite as much as that. In order, therefore, to make assurance doubly sure, I put in £150 in respect of the extra interest we might have to pay until the Tothill Street site is disposed of.

I need hardly say that I could not bring this statement before you with any assurance or with any feeling that I was doing my duty to the Institution if it were simply a question of embarking upon a business which wiped off our £4,500 annual increment. But we embark upon this undertaking with the idea, that some one has to step forward and take the risk in order to make a great gain to the Institution, because it

Mr. Hammond. is felt that it is impossible, looking at it purely from the financial point of view, that such a building would not bring in a revenue.

The President. The PRESIDENT: I will now move:—

> "That the purchase of the lease of the site and building known as 'The Medical Examination Hall,' situate on the Victoria Embankment, London, W.C., now the property of the Royal College of Physicians of London and the Royal College of Surgeons of England, for the sum of £50,000, be sanctioned and approved, and that the Council be authorised to sell such of the investments of the Institution and to make such other financial arrangements (including the disposal of the site in Tothill Street, now owned by the Institution) as the Council may consider necessary for the above purpose."

I call on Mr. Mordey, the President-Elect, to second the resolution, and in doing so to give a further explanation of the history of the affair.

Mr. Mordey. Mr. W. M. MORDEY: Mr. President and Gentlemen, I am very happy that my first public duty as the President-Elect is to support a proposal, which, if carried, will, I feel sure, be for the lasting good of the Institution of Electrical Engineers and of electrical engineering generally. In the first place, I would like to read a letter from one of our original members. You all know what an interest Lord Crawford and Balcarres took in the early days of electrical engineering; he has written this letter:—

> "I regret that I shall not be able to attend the meeting called "for the 30th. I must, however, write a line of congratulation to "the Institution on their acquisition of so fine a home, especially "when I think of the first thoughts of its formation in my old "laboratory in a mews behind Green Street, Park Lane, all now "swept away, and of the first *soirée* which was held in my labora-"tory in Greek Street, Soho. I believe that now I am the senior "surviving officer of the Society, as I was Vice-President to Sir "William Thomson (one of our first Presidents), and as such I "offer my congratulations.—Very faithfully yours, CRAWFORD." *

We may pass from that very early period of our formation in 1871, and of Lord Kelvin's first presidency of 1874 to 1893, when the Institution had arrived at years of discretion. In the Annual Report for 1893 † there is a passage which, with your permission, I will now read: "Although the Council hope that the Institution, by the continued "liberality of the Institution of Civil Engineers, may enjoy for many "years to come the privilege of meeting in this hall, they feel it prudent "to provide for the time when it may become necessary that we should

* Lord Lindsay, now Lord Crawford and Balcarres, was actually the first Vice-President of the Institution, holding that office for three years, 1872–3–4, during the presidencies of Sir William Siemens, Frank Ives Scudamore, and Sir William Thomson.

† "Report of the Council," vol. 22, p. 570, 1893.



FIG. 1.—View of the Building from the Victoria Embankment.

"possess premises, with a lecture hall, of our own; and they propose Mr. Mordey.
"therefore to transfer a portion of the invested funds of the Institution
"to a Building Fund, and to add thereto each year a certain amount
"out of that year's surplus revenue." *

That was the beginning of the Building Fund. It began with a contribution of £3,000. I am glad to read that passage, because it gives me an opportunity of referring to the great debt of gratitude that we as an Institution owe to the Institution of Civil Engineers. When we have, as I hope we very soon shall have, a home of our own, I am sure our sense of gratitude to the Institution of Civil Engineers will be just as keen as it has been during these last thirty-seven years, during the whole of which time they have, with great liberality and public spirit, allowed us the use of their meeting-hall. The extract I have read clearly shows what the Council then thought was its first duty—to put aside its surplus funds to provide as soon as possible a home for the Institution. The need for that home has grown with our growth, and our growth has been very great, as you will realise when I remind you that we now have 6,048 members. It is interesting to note that no less than 1,230 of our Members, Associate Members, and Associates are affiliated to one or other of the Local Sections which have been established in the provinces, having Birmingham, Dublin, Glasgow, Leeds, Manchester, and Newcastle as their centres. Our membership is not very far behind the Institution of Civil Engineers, the great parent Institution, which has about 8,500. Ours is, I believe, the second engineering institution in this country in numbers, and, as electrical engineers, we also think we are not behind that position in usefulness and in importance. I think it is not a right or seemly thing that an Institution of this character, dealing as it does with a branch of engineering that is already very important and is getting to be more and more so, should be the recipients of the hospitality of other societies. We want a home of our own for many purposes. We want a theatre for our general meetings, rooms for our Council meetings and students' meetings, and we want accommodation for conferences, for committee meetings, for our large and valuable library, possibly for our museum, and of course for our office and editorial work, including the *Journal* and *Science Abstracts*: and perhaps I may go further and say that for certain social purposes we should like to have room and accommodation. We want a place where our members from country or town can meet before and after the general meetings, or whenever they wish, for the purpose of social intercourse. The Building Fund, as I have said, was started in 1893 with £3,000. During the next eleven years money was put to it as it could be spared, the average for those eleven years being nearly £1,500 a year. Then we come to 1904, when we bought the Tothill Street site. It may be said that it was unwise to buy the Tothill Street site only four years ago and not to use it. I do not think it was unwise. Sites in Westminster were getting very scarce and very dear, and

* Journal, vol. 22, p. 575, 1893.

Mr. Mordey. we took the best site that could be got in Westminster within our means at the time. We now realise that we can do better. You will realise the difference between that site and this when I remind you that the area of the Tothill Street site is 5,200 ft. and that this site is over 20,000 ft.; and when I tell you further that in the preliminary design that was got out for a building there a floor space of 10,000 ft. was all that could be obtained, including corridors and the theatre, and that here, without reckoning the theatre and the very ample corridors and halls, we have about 40,000 sq. ft. of space. So that I think you will agree with me that, as we believe the Tothill Street site will not long be a burden on the Institution, we shall be very wise if we desert it for this very much better one, especially as it gives us what we want—a building now, without the delays and the anxieties of having to build. It has been said that "who goes a-borrowing goes a-sorrowing." I think it more true—although it does not rhyme—to say, "who goes a-building goes a-sorrowing." Every one who has had experience of putting up public institutions will agree that it is a distinct advantage that we shall not have to go a-building. You have heard from the able and clear statement of the Treasurer how we stand as to the Tothill Street site. That site has paid a fair interest as an investment. Further than that, we are assured by competent authorities who know the value of land and property in Westminster, that the Tothill Street site has increased in value; so that we believe that when the time comes to sell the Tothill Street site—and we need not hurry about it—the members will find that the Institution was not unwise in buying it. We now come to the question of the obtaining of this building. There is, I believe, an idea present in the minds of a good many members that this transaction has been forced forward too quickly. We have acted quickly, but we believe we have acted wisely. I should point out that the rapid action has in reality only been the culmination of fifteen years of careful preparation. It was necessary to act quickly. The building was in the market. Five weeks ago the Council, after having decided to add about £13,000 to the Building Fund, appointed an exploring party—a small committee—and sent it out with instructions to act, and to act quickly if possible. This meeting to-day is the result. That exploring party found this building. It found other buildings, and considered many sites in Westminster and in other parts of London.

An important public body was our competitor for this building; but we obtained from the Colleges of Physicians and of Surgeons a definite option for three weeks at a definite price. We felt sure that if we did not exercise that option the opportunity would be gone. We went into the matter very carefully, we made comparisons, and we had all necessary professional advice. The only other site that the Council thought suitable was the Imperial Theatre site in Westminster. It is true that is freehold, whereas this only has a lease of seventy-six years; but that site, with a new building on it—because the existing building would have to be pulled down—would, after making proper allowance as capital for the ground rent here, cost very nearly twice as much per

square foot as this site with the building on it—with an existing building practically ready for use—which we think is admirably suited to the purposes of this Institution; and when I say the purposes of this Institution I use the term in the broad sense, not merely meaning our own purposes, but the other purposes which we have had in mind. To enable you to compare the areas of sites, may I give you one or two figures for other Institutions. The site here is over 20,000 sq. ft. The

Mr. Morsey.

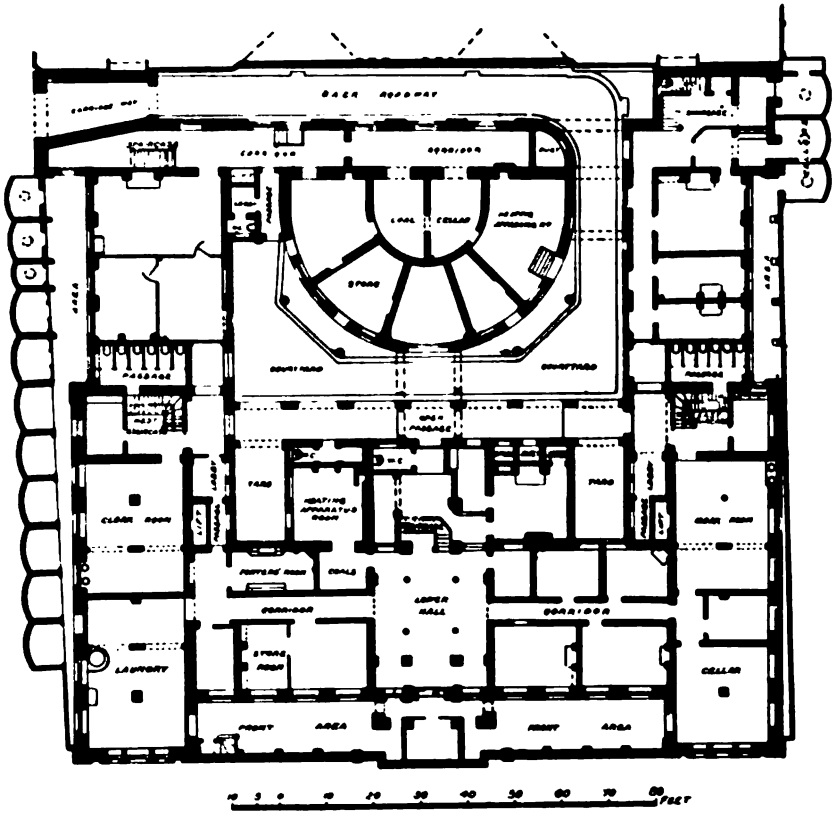


FIG. 2.—Basement.

present Institution of Civil Engineers is about 10,700 sq. ft.; the Mechanical Engineers, 5,000 sq. ft.; and the Society of Arts, 2,500 sq. ft. The room space, including the theatre, is over 40,000 ft.; the Civil Engineers is 15,000 ft.; and the Mechanical Engineers, 9,200 ft. The theatre is, we think, rather small; but it is probably large enough for our purposes for some time. In that connection I wish to explain the brief statement in the invitation to this meeting, that the theatre

Mr. Mordey. can easily be enlarged. You will see that it is a horseshoe in form. The flat side is on one side of the building, and the horseshoe is in the quadrangle. If you look at the building or at the drawings on the wall * you will see it will not be a very serious matter to increase the size of that horseshoe to any extent that the area will allow, or even to remove the horseshoe altogether and to roof in the whole of the quadrangle. In that case we should have one of the finest halls in London. In addition to this theatre we have four floors and a basement, and the average is 7,700 ft. each. It may or may not be wise to enlarge the theatre, but I merely draw your attention to that point as I understand there has been some uncertainty as to what it would involve. There are seventeen rooms in this building, in addition to the theatre, ranging from nearly 1,000 ft. to 3,000 ft.; they are handsome, large, well-lighted rooms. I need not say anything about the position; you can judge of that for yourselves. There is no finer site in London. I do not think I need say much either about the accessibility of the building. It is one of the most central places in London. It is at the junction of the tramways, north and south; it is within a very short distance of some of the principal railway stations; it is rather more accessible than any Westminster site. It may be said that we ought to remain in Westminster, the engineering centre; but it is possible to worship the Westminster fetish too fervently. Here we are more or less midway between Westminster and the City; we are close to a district which is becoming quite an electrical engineering centre—we are quite close to the Law Courts; I think that in every way we are very well placed indeed as regards convenience of access for our members generally. As to the building, we made it a condition of the contract that we should have a report from an architect. Mr. Ayling, who was largely concerned in the building of the Institution of Civil Engineers, undertook that duty and gave us a very full and careful report, which is entirely of a satisfactory character. I am sure anybody who has gone through this building will agree that structurally it is in a very good state of preservation indeed. The architect reports that £50 is the total expenditure necessary to put the building into a sound condition; there are only one or two little things that require doing. I am not, of course, speaking about the decoration or anything of that sort. I fear I am taking up too much time, but I think I ought to say something on the question of the use of a common building. It has been objected that we ought to have combined with other societies, and have done what has been done in America—erected a common building for engineering societies. Well, we have not had Mr. Carnegie to rely on here. His generosity in this country has taken other directions, and we have had to rely on our own resources, which, perhaps, is the best thing in the end. We have not, therefore, been able to step into a building ready made for us. But the question of combining with other societies has not been overlooked, and on various occasions during the last few years other societies have been approached with a view to

* For reproductions of these drawings see Figs. 1 to 7.

finding some common ground for dealing with this question of a home for engineering societies, but nothing has come of it; there were no definite results. Possibly if we had had time—I think it would have taken years—we might have made some arrangement with other societies, but it was not possible to do it in any short time; it is always difficult when there are many interests to consider. Mr. Mordey.

Here we had the opportunity of getting a good building for ourselves

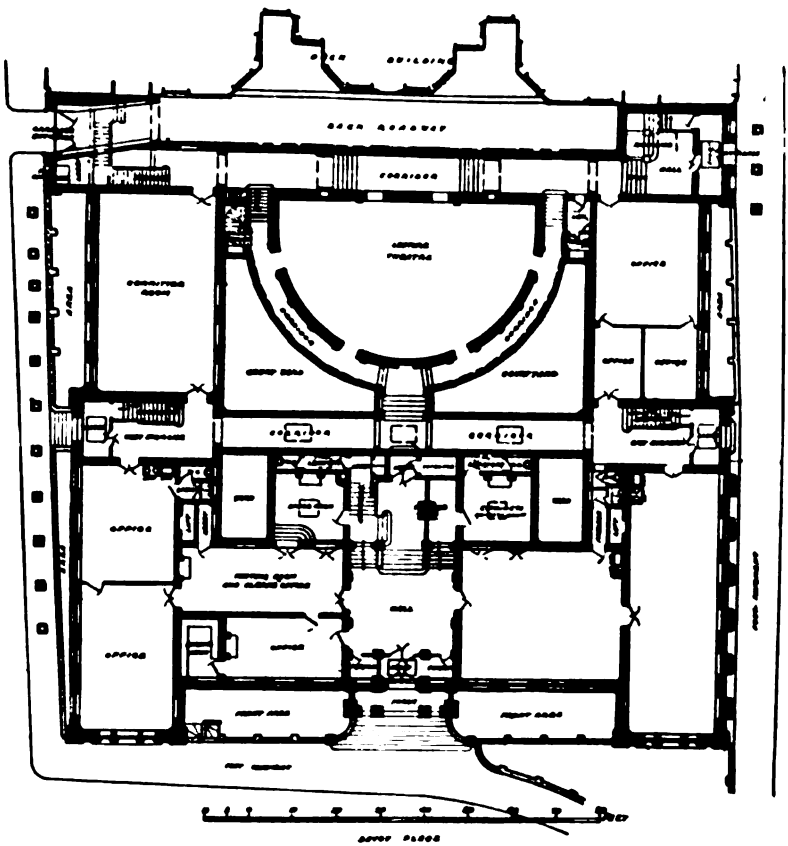


FIG. 3.—Ground Floor.

and one that gives us our own home and the means of co-operating with other societies. And it gives us the means of being hospitable as others have been hospitable to us. It may be objected that the space we do not need may be a burden on the Institution. We do not fear that for one moment, although there is a great deal of space that we shall not need ourselves for many years. If that space is taken over by kindred societies at the same rate as the three rooms that are now

Mr. Mordey. let for £650 a year, it will bring in some thousands of pounds a year. The Council thinks there is no risk in any serious sense of the word in connection with the disposing of that space. It is not in any case a matter that need be hurried. If we do not let anything except the three rooms that are now let we shall just about pay our way, with the normal rate of increase of our membership. We believe, however, that the increased facilities the building will give and the increased usefulness, prestige, and standing of the Institution, will lead to a rapid growth of our membership, and this, in spite of the higher standard that we are exacting.

One important thing I must not omit to mention. No increase of subscription will be necessary, nor any general levy on the members. The Building Fund, which has existed since 1893, will continue to exist, and I am asked to draw the attention of members specially to that fact. That Fund has already received about £2,000 in voluntary subscriptions, and it is believed that many more members will now wish to add to it either by annual contributions or otherwise.

There is nothing necessary now, sir, but the approval of this meeting and your signature to make this building the Home of the Institution of Electrical Engineers. Gentlemen, I have very great pleasure in seconding the proposal which has been made by the President.

Sir Joseph Swan. Sir JOSEPH SWAN, F.R.S.: I feel that the subject has been so completely gone into from every point of view—from the financial point of view by our Honorary Treasurer, and from every other point of view by our President-Elect—that very little remains to be said, beyond the expression, which I am very glad to make in the most unqualified way, of my confidence in the wisdom of the Council in having made this proposition, and having brought it to the position of almost complete consummation, as has just been stated by Mr. Mordey.

Mr. Ward. Mr. GEORGE G. WARD (Local Hon. Secretary for the United States): Mr. President and fellow members, although I am a stranger to most of you, I may be permitted to say that I have been connected with the Institution as an Associate and Member since 1874, and have had the honour for more than thirty years of representing it in the United States as its Honorary Treasurer and Secretary. When I was elected there were two hundred members, and now our President-Elect says there are more than six thousand on the Roll. These figures seem to me to prove conclusively the necessity of having a building for ourselves. It has been stated that the building in which we are met can be made most convenient for our purpose. We are all most grateful to the Civil Engineers for their kindness in granting this Institution the privilege of using their building; but, gentlemen, this Institution is doing too great a work to be the tenant of anybody else. Its influence goes to every quarter of the earth. Gentlemen, the moment has arrived: do not miss the opportunity. I have much pleasure in supporting the motion.

Mr. Barton. Mr. E. C. BARTON (Local Hon. Secretary for Brisbane): I have little to say, except to congratulate the Institution heartily on the

opportunity, and, I hope, on the result of this meeting, and that in Australia we have always looked upon this Institution as a great soul that had no body to reside in. It will be a great pleasure to us now to think that the Institution will have so fine a building for its permanent accommodation. Mr. Barton.

Major P. CARDEW, R.E.: I am an old member of this Institution and I do not often trouble you with remarks; but I think when such a very Major Cardew.

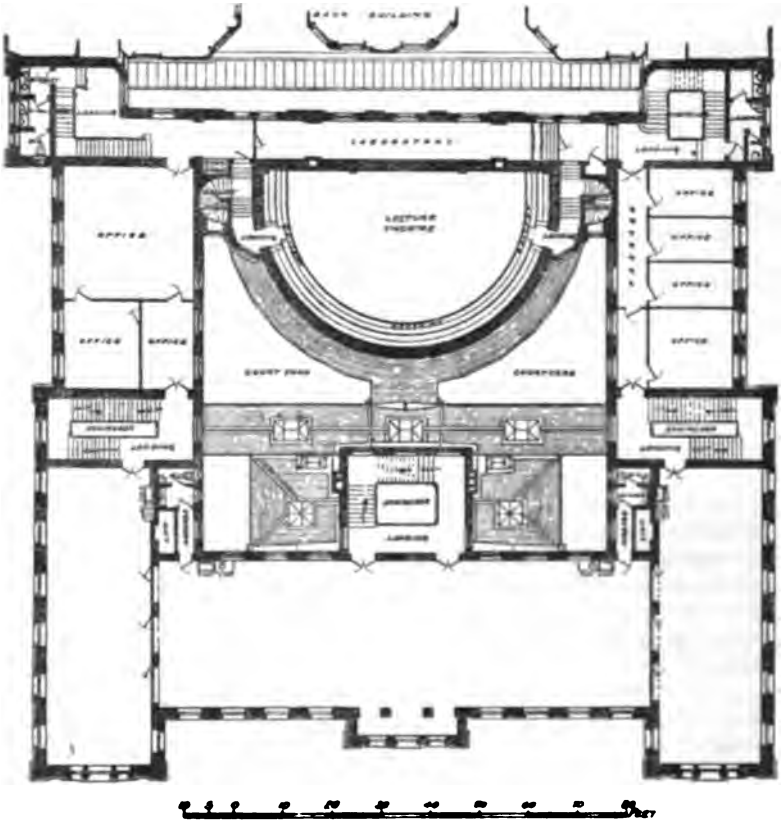


FIG. 4.—First Floor.

momentous decision is to be taken, it is a time when age and experience may put in a few observations. I take it that the question to-day is not whether the Institution is to have a building, but whether this particular building is so exactly suited to our needs as to warrant what must appear to be rather hasty steps being taken to acquire it. I have served on this Council for many years, and it seems to me a departure from our usual proceedings to take such a step as this in such a

Major Cardew. headlong way. I do not want to raise unnecessary difficulties, but I cannot understand the great haste. Surely a question involving the immediate expenditure of £50,000 should be thoroughly considered, and I suggest that a statement showing the pros and cons should be submitted to the members, and that the voting should be in writing. It seems to me that that would be more in consonance with careful progression.

Mr. Roberts. Mr. MARTIN ROBERTS: In my opinion the scheme is an ill-considered one, and this building is larger than we want. The building which the Institution of Civil Engineers is just about to vacate covers an area of about 10,700 sq. ft. This has an area of over 20,000 sq. ft., and from what I have seen of it, it appears to me quite unsuitable for our requirements. Can the Council seriously say that a building on lines similar to the Institution of Civil Engineers would not meet all the needs of this Institution? Next, I suggest that it will seriously cripple the resources of the Institution to have to meet the very heavy liability set out in the Treasurer's statement. The Institution will not be able to do what it has done in the past, and what we all hope it will be able to do in the future, in furthering the interests of the electrical profession. I therefore beg leave to propose as an amendment:—

> "That the resolution circulated to the members of the Institution be referred back to the Council for further consideration."

Mr. Esson. Mr. W. B. ESSON: I wish to support the last speaker. I do not see why this matter should not be referred back to the Council for consideration, or should not be deferred for some years if necessary. We need not be in such a hurry to get into a home of our own; we have done very well for a long time without it. It has been said that we want more accommodation—Mr. Mordey has put it very forcibly—and I agree with all he said. We want to be able to entertain, and we want a place which is worthy of the Institution, but there is no particular hurry about it. For these reasons I second Mr. Roberts' motion, that the matter be referred back for further consideration.

Mr. Gaster. Mr. LEON GASTER: I would like to say that I think this building is admirably suited for the accommodation of kindred societies in a common home.

Mr. Sharp. Mr. SIDNEY SHARP: There is one view of the question which presents itself to me. The assets of the Institution amount at present to £45,000, and the funds increase annually by about £5,000. In eight years we shall have £85,000, and we might make a better use of it then than with the smaller capital we have now. We shall now run into debt, and the Council will not only have to conduct the affairs of the Institution, but they will also be in the position of landlords and have the trouble of keeping the parts of the building they do not propose to use fully sub-let to tenants.

Mr. R. S. ERSKINE: The figure of £170 was mentioned as the cost to the present owners of keeping this building in order. I have had a certain amount of experience with regard to property in London, and if that figure includes the repainting I think it cannot be done at that price. The amount allowed for cleaning and household expenses also appears to me to be much too low. Mr. Erskine.

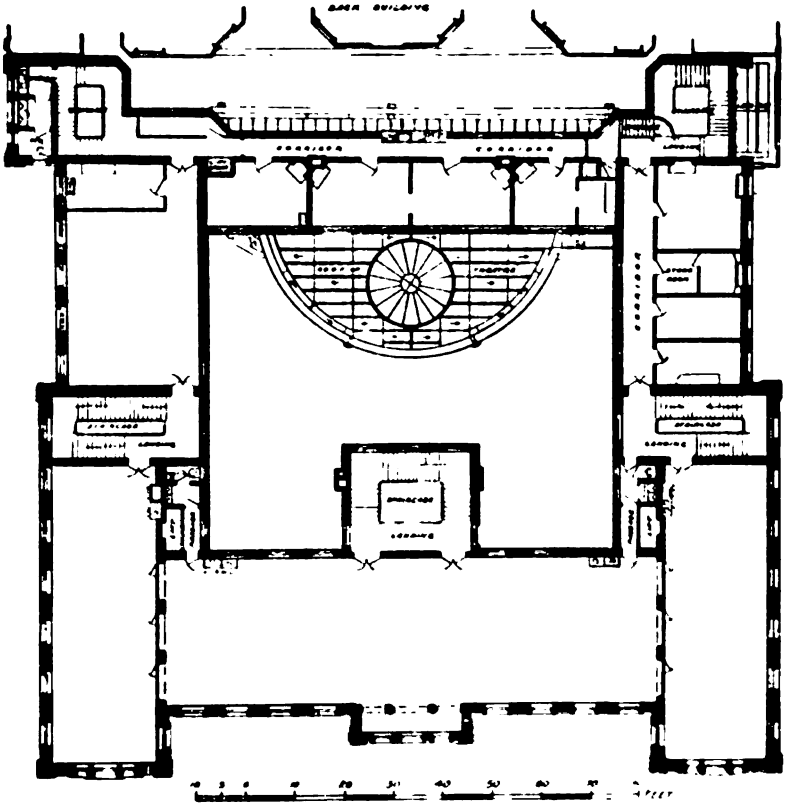


FIG. 5.--Second Floor.

The PRESIDENT: The figure of £170 is for the annual upkeep of the building. The painting has to be done only every seven years. The President.

Mr. ALEXANDER SIEMENS: To a certain extent I was the moving spirit, or at any rate, I strongly urged upon the Council that they ought to act quickly in this matter. In matters like these it is not possible to consult every one of the 6,000 members. I understand that the Council is elected for the purpose of conducting the affairs of the Institution, and in these sort of affairs one has to act quickly. You have been Mr. Siemens.

Mr. Siemens. told that the Building Fund was started in 1893, and from that time every member of the Council has always kept a weather eye open to see how and when a building or a site could be acquired for the Institution. Sites in Westminster are not very plentiful. I have some personal experience in this matter, because my firm (Siemens Brothers) lately looked out for a site on which to build new offices if they possibly could, and the result of the inquiry was that they could not find one which was at all suitable for building offices. Then the Institution of Civil Engineers has been looking out for a site in Westminster ; and it has only been after the greatest possible trouble, and after three or four years negotiations with the Government, that they obtained one. Their new site is 138 × 138 ft., or roughly, 20,000 sq. ft. ; and that increased space was obtained because it was found that the present Institution building on a site of 10,700 sq. ft. was not sufficient for the requirements of the Institution—that especially in office accommodation and such things it was absolutely necessary to have more room. Sites in Westminster cannot be obtained unless one pays very heavily for them. I would strongly recommend the members to accept this building and to reject the amendment which has been moved.

Mr. Robinson. Mr. MARK ROBINSON : A few years ago, until the pressure of other duties forced me regretfully to resign the position, I had the honour to be a member of the Council of this Institution, and even at that time the question of a new building for the Institution was under constant discussion, and the urgency of the matter very forcibly presented itself to all the members of the Council. There is nothing new in our seeking a home, nor in our considering the question an urgent one. One speaker has suggested we should wait for four or eight years, when we shall have saved up more money. Why did he not suggest sixteen years, and more saving still? Perhaps it would suit him, but some of us are "getting on," and would like to see the Institution in a home of its own, and of our own, before we resign our membership of all things. The course unanimously recommended by the Council, is, to say the least, entitled to very favourable consideration, and I beg heartily to support it.

Mr. Aitken. Mr. JAMES AITKEN : I understand that the remainder of the lease of the building is seventy-six years, and at the end of that time the Institution will have to give it up after having spent practically the whole of its capital resources on its acquisition.

Mr. Hammond. Mr. R. HAMMOND : Provision is made for an Amortisation Fund of £200 a year, which will replace the capital of £50,000 in seventy-six years.

The President. The PRESIDENT : I will now put the amendment proposed by Mr. Roberts, seconded by Mr. Esson, "that the question of the purchase of this building be referred back to the Council for further consideration."

The amendment was then put, and was lost by an overwhelming majority.

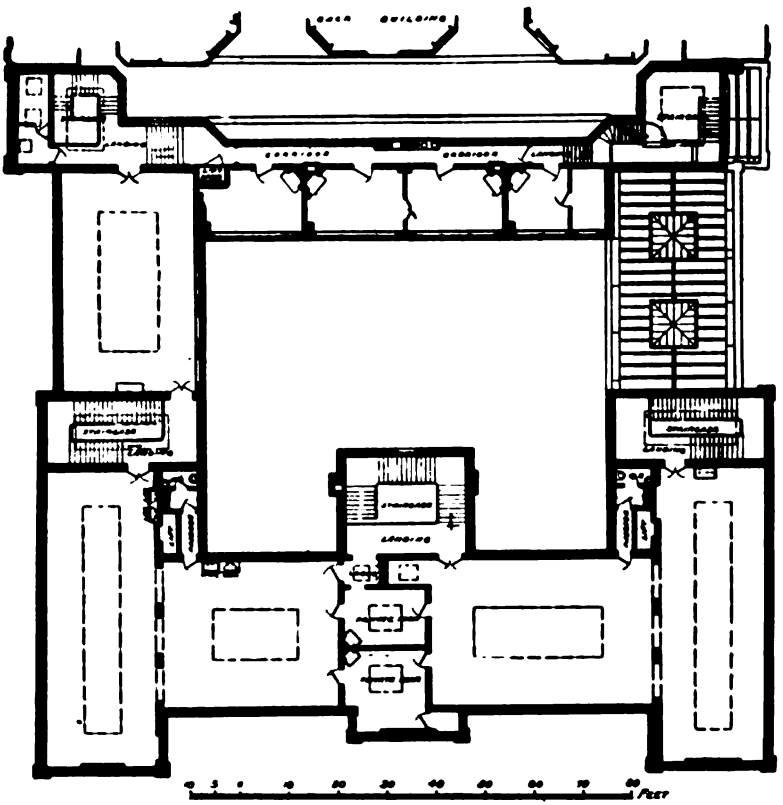


FIG. 6.—Third Floor.

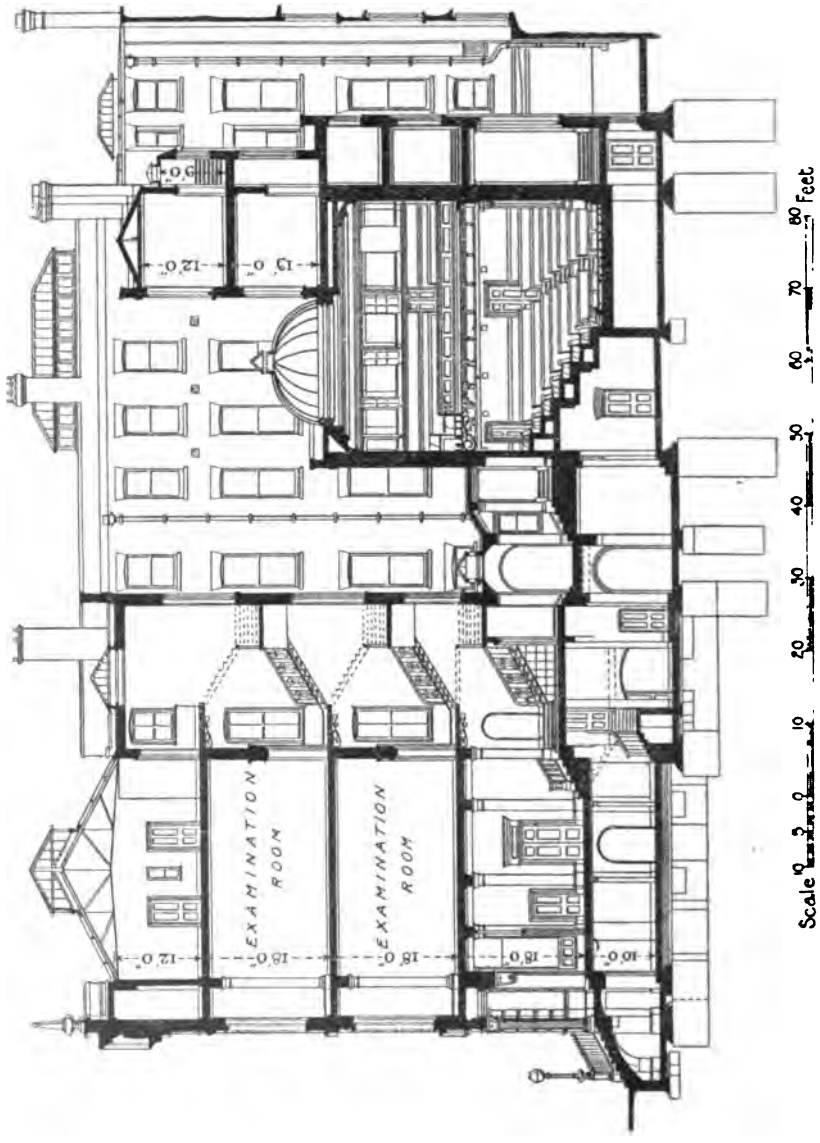


Fig. 7. Section

The President then put the resolution to the meeting and it was carried unanimously. The President.

The PRESIDENT: Gentlemen, I now declare the resolution to have been carried, and in the name of the Council I thank you.

The meeting then terminated.

The accompanying illustrations are from a photograph taken recently, and from reproductions of the architect's plans, which were shown at the Special General Meeting.

OBITUARY NOTICES.

WILLIAM THOMSON, BARON KELVIN OF LARGS, O.M., G.C.V.O., died at his residence, Netherhall, Largs, in the County of Ayr, on December 17, 1907. He was an Original Member of the Institution, and was President in 1874, 1889, and 1907. He was elected an Honorary Member in 1899. A full account of his life and work is contained in the first Kelvin Lecture by Dr. Silvanus P. Thompson, F.R.S., *Journal*, vol. 41, p. 401. A portrait of Lord Kelvin was published with part 188, vol. 40 of the *Journal*.

ARCHIBALD CAMPBELL CAMPBELL, BARON BLYTHSWOOD, died on July 8, 1908, at his seat, Blythswood House, Renfrewshire. Lord Blythswood was born in 1835, and was the son of Archibald Campbell, of Blythswood. He served with his regiment, the Scots Guards, in the Crimea, where he was severely wounded. On the death of his father in 1861 he retired with the rank of Lieutenant-Colonel, and immediately devoted himself to the Auxiliary Forces. For some time he sat in Parliament as member for Renfrewshire and West Renfrewshire, which latter constituency he held till 1892, when he was raised to the peerage as Baron Blythswood. Lord Blythswood was a devoted student of science and did much useful work, especially in physics. After the discovery of radium some interesting experiments were carried out in the laboratory which he equipped at Blythswood.

He was a leader in county politics and an active statesman. He was elected an Associate of the Institution in 1883.

RICHARD VICARS BOYLE, C.S.I., died on January 3, 1908, from failure of the heart. Mr. Boyle was born in 1822, being the third son of Mr. V. A. Boyle, of Dublin. He received his early training as a pupil of Charles Vignoles, F.R.S., and subsequently was engaged on railway construction work in Ireland and England, and in Spain. In 1853 he was appointed District Engineer on the East Indian Railway with headquarters at Arrah, Bengal. In the Mutiny he played a conspicuous part, holding out for eight days in his fortified house with 80 men and a party of 50 Sikhs against 3,000 mutinous troops. After his relief Mr. Boyle acted as Field Engineer to one of the British columns. For his services he was awarded a Mutiny medal, a grant of land at Arrah, and subsequently the Companionship of the Star of India. From 1872 to 1877 he held the appointment of Engineer-in-Chief to the Imperial Government Railways of Japan. He was elected a Member of the Institution in 1874.

ERNST DANIELSON, of Westeras, Sweden, died in September, 1907. Born on January 19, 1866, he studied at Upsala, and passed through the works of the Stockholm Electric Company, and then through the Technical High School at Stockholm. For some time he held the position of Assistant Engineer to the Stockholm Electrical Company, and in 1890 he went to the United States, where he entered the service of the Wenström Consolidated Dynamo and Motor Company, at Baltimore, and afterwards joined the General Electric Company of Schenectady. In 1892 Danielson was offered the position of Chief Engineer to the Almanna Svenska Elektriska Aktiebolaget at Westeras, which position he held until 1895. He then started practice as a Consulting Engineer in Stockholm, and among other important works for which he was responsible was the scheme for utilising the water-power of the Trollhattan Falls. Subsequently he became Technical Director of his company at Westeras, but was obliged to resign in 1903 on account of failing health.

His most important work was in connection with the 3-phase system and its utilisation for power transmission. During his two years' stay in America he had exceptional opportunities for making exhaustive practical tests with the 3-phase system, and became convinced of its practical importance. On his return he devoted considerable attention to the design and development of 3-phase apparatus. His first machine fully realised all expectations, and on the basis of experiments with this the theory was still further developed, and Danielson was able to draw up his plans for the use of the 3-phase system for power transmission on a considerable scale. The first work to be carried out was the well-known power transmission installation at Hellsjon-Grangesberg, the success of which led to several other power schemes, such as Hofors, Boxholm, etc. The fact that after a lapse of twelve to fourteen years, during which numerous developments have taken place in electrical science, these installations of Danielson are still working, bears striking testimony to his engineering judgment and ability.

He was elected a Foreign Member of the Institution in 1894.

JAMES EDGAR died at his residence at Wrexham on December 17, 1907, in his 64th year. He was the eldest son of Captain Thomas Edgar, and in his early years was appointed Postmaster of the Borough of Wrexham, which position he filled for nearly a quarter of a century with conspicuous ability.

Several inventions were brought out by him, among which may be mentioned one for the purpose of establishing telephonic communication between the guards and engine-drivers of trains, in which he utilised the railway metals as conductors. He was elected an Associate of the Institution in 1878, and an Associate Member in 1899.

THE VERY REVD. FATHER E. LAFONT, S.J., C.I.E., whose death occurred at Darjeeling Sanatorium on May 10, 1908, was a

Foreign Member of the Institution of Electrical Engineers, and Chairman of the Calcutta Local Section since 1899. Born in Belgium in March, 1837, he had completed his 71st year, of which forty-three were spent in India. He visited Europe only on two occasions: once in 1878 he went to recruit after a severe illness; on the second occasion he went for scientific purposes and to see the 1900 Paris Exhibition. He owed his name as "Father of Science" in India to his unequalled power of popularising his subject, and to the depth of his knowledge of experimental physics.

He was appointed Rector of St. Xaviers, Calcutta, in 1873, and held that position, except for an interval of a few years, till 1904, when his health began to fail. For nineteen years he gave weekly lectures to the Indian Association for the Cultivation of Science, and remained till his death its Senior Vice-President. He was an active member of the Senate of the Calcutta University, of which he was made a Fellow in 1877, and was President of the Faculty of Arts.

In recognition of his services to Science he was created in 1880 by the Viceroy, Lord Lytton, a Companion of the Indian Empire, and through the kind offices of Lord Dufferin he received the decoration of Officier de l'Academie de France. His own King Leopold, as a mark of high esteem, made him in 1898 a Knight of the Order of Leopold, and finally Lord Minto, the present Viceroy, bestowed on him the honorary degree of Doctor of Science.

To Father Lafont St. Xaviers College owes its fine meteorological and solar observatory and its well-equipped physical laboratory—second to none in India. For the latter—almost in the latter—he lived, and when age compelled him to abandon his beloved works, his friends felt that the end was drawing near. Yet what strength was left he devoted to the very last to that other work in which he excelled and which was always his first object—the teaching and expounding of the great truths of religion.

Besides being a distinguished scientist, the late Father was an eloquent preacher, and his many gifts, combined with his charming manner, rendered him popular among all classes of society.*

JAMES NELSON SHOOLBRED died on September 8, 1907, at Kirkwall, in Orkney. He was born at Bangor, in Wales, in 1835, and became a pupil of Charles Vignoles. Mr. Shoolbred achieved a considerable reputation during the earlier developments of electrical engineering, and was regarded as one of the pioneers of municipal electrical engineering enterprise. He acted as Consulting Engineer to many municipalities, and the first work of this character which he took in hand was in connection with the lighting installation for Bradford in the year 1888, before which date only ten towns in Great Britain were lighted by electricity.

Two years later he was acting as Consulting Engineer to the Brighton

* The Secretary is indebted to Mr. F. J. Robins, A.M.I.E.E. of Calcutta, for this brief account of Father Lafont's life and work.

Corporation, and in 1895 in the same capacity for Birkenhead, in 1897 for Accrington, in 1898 for Stockport, and in 1899 for Doncaster. He was Consulting Engineer to these Corporations not only in their general works, but he also supervised the completion of the electrical installations until they were taken over by the several municipalities. He appears also to have acted for many other towns when seeking provisional orders or Parliamentary powers, and in many cases success was due to the advice given by Mr. Shoolbred in the preparation of the proposals.

Two papers were contributed by him to the *Proceedings* of the Institution on "The Measurement of Electricity for Commercial Purposes," read in 1883, and the other on "Electric Light on the Forth Bridge Works," read in 1885. Mr. Shoolbred was also a member of the Committee appointed by the Institution in 1882 to draw up rules and regulations for the prevention of fire risks arising from electric lighting, and assisted in the work of publishing the first edition of the present Wiring Rules of the Institution. Mr. Shoolbred was also an expert in harbour engineering work, and was closely connected with the construction of the Mersey Estuary. He was elected a Member of the Institution in 1881.

HANSON TOPHAM met his death as the result of an accident on November 7, 1907. Mr. Topham was born at Bradford, Yorkshire, on July 25, 1876, and after serving a period of apprenticeship as Engineer he studied for five years at the Central Technical College, South Kensington, under Professor Ayrton and Professor Perry, and was successful in gaining a Whitworth Scholarship. Later he entered the service of the City Road Works of the Brush and Provincial Electric Lighting Company. He was then appointed by Messrs. Bramwell & Harris to carry out works at Ilkeston and Bishop Auckland, and subsequently he was in charge of the electrical installations in connection with the boring of the City and South London Company's Tube between Islington and Euston. At the time of his death he was in the service of the Newcastle-upon-Tyne Electric Supply Company for whom he was supervising some boring operations in connection with the Carville Electric Power Station. On the night of November 7th an explosion occurred which wrecked the air-lock in which the men were working, killing Mr. Topham instantaneously and causing severe injury to others on the works.

Mr. Topham was elected an Associate Member of the Institution in 1905.

FRANCIS HUGHES WEBB, late Secretary of the Institution, died at his residence in Hampstead on May 17, 1908. Mr. Webb was appointed Secretary of the Institution in 1878. He held that office for twenty years, until his retirement in 1898. He was born in London in 1824, and educated at University College School and at the École Normale, Brussels. Subsequently he spent two years in Germany with

John Player, Engineer to the British Nassau Iron Company, and was afterwards appointed Clerk of the Audit Office of London, Brighton and South Coast Railway. In 1844 he became resident Secretary and Librarian to the Royal Institute of British Architects, which post he resigned in 1850 in order to enter the service of the Electric Telegraph Company as assistant to Edwin Clark, then Engineer-in-Chief. The following year Mr. Webb accepted the appointment of Private Secretary to the chairman of that company, John Lewis Ricardo, M.P., with whom he remained until the year of that gentleman's death in 1862. During that period he was brought much into intimate contact with many of the most eminent civil engineers and contractors of the time. In 1865 he again entered the service of the London, Brighton, and South Coast Railway as Assistant Secretary, but resigned in 1867 to renew his association with Mr. Edwin Clark, then largely engaged in engineering work. Mr. Webb was secretary to the Nova Scotia and New Brunswick Railway Company, the Malta Hydraulic Dock Company, and the Monte Video Harbour Improvements Company. On his appointment in 1878 as Secretary to the Society of Telegraph Engineers he did not at once relinquish the other appointments he was holding at the time, but in 1885, owing to the growth of the Society, he found it necessary to devote his entire attention to the work of the Society. During his Secretaryship (in 1883) the Institution, originally called "The Society of Telegraph Engineers," was incorporated under the altered name of "The Society of Telegraph Engineers and Electricians," and in 1889 the name was changed to the one by which it is now known.

After his retirement Mr. Webb remained an Associate, and continued to take a close personal interest in the progress and welfare of the Institution with which he was so long and honourably connected.

JOHN WOODSIDE died on February 2, 1908, at Belfast. Mr. Woodside carried out a number of important electric installations, including numerous mills and factories in the north of Ireland. At the time of his death he was in his 37th year.

Mr. Woodside was elected an Associate Member of the Institution in 1901.

Since the date of the Annual General Meeting, the following deaths of Members have also been reported :—

ELEUTHERE ELIE NICOLAS MASCART, Membre de l'Institut France, Hon. Member of the Institution since 1901. Died August 25, 1908.

EMIL NAGLO, Past President of the Elektrotechnischer Verein, an Original Member of the Institution. Died September 12, 1908.

Notices of their careers will be published in due course.

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1908.

EXPLANATION OF ABBREVIATIONS.

[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

[*d*] signifies a reference to remarks incidentally introduced into a discussion on a Paper.

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